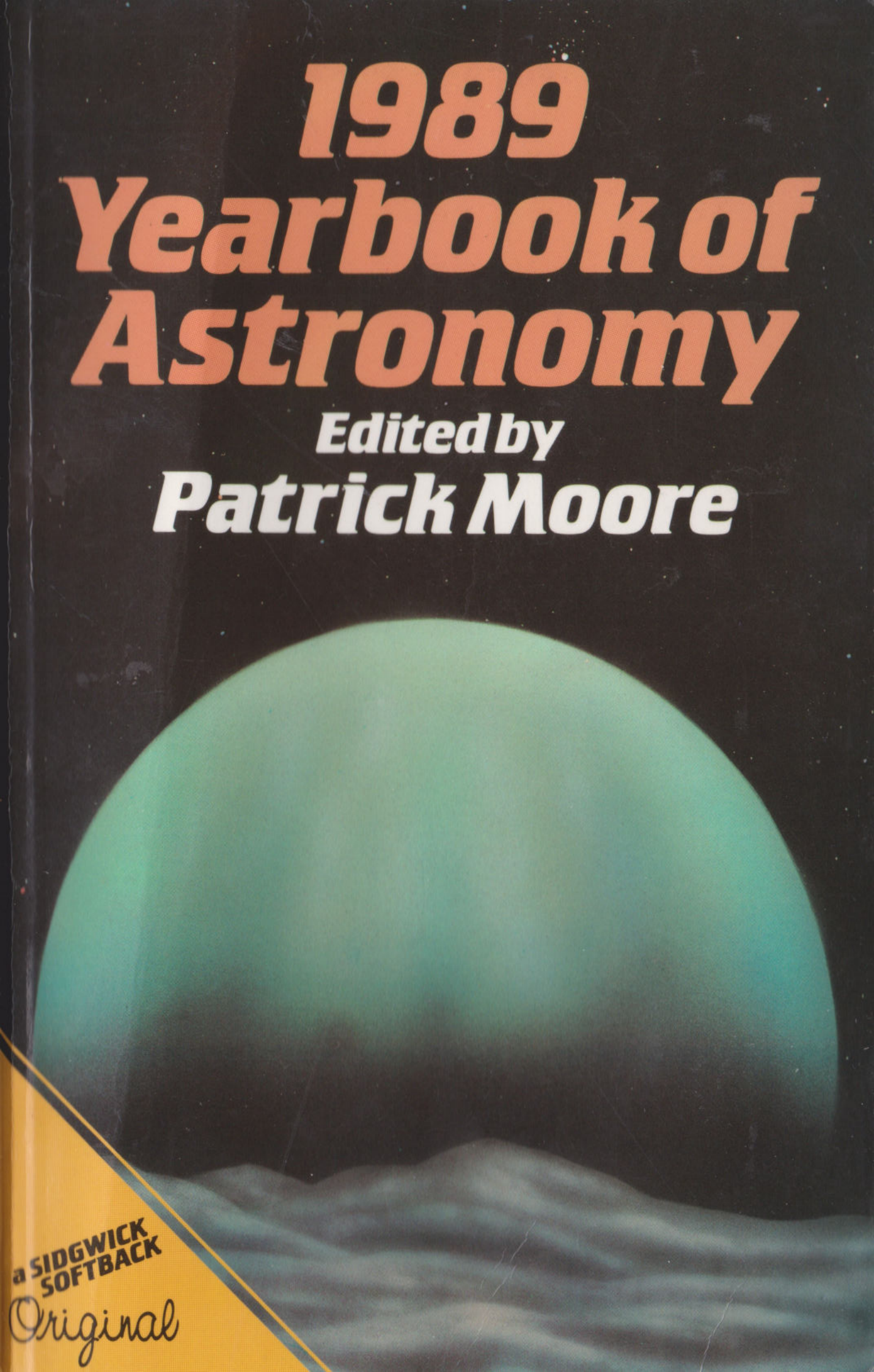


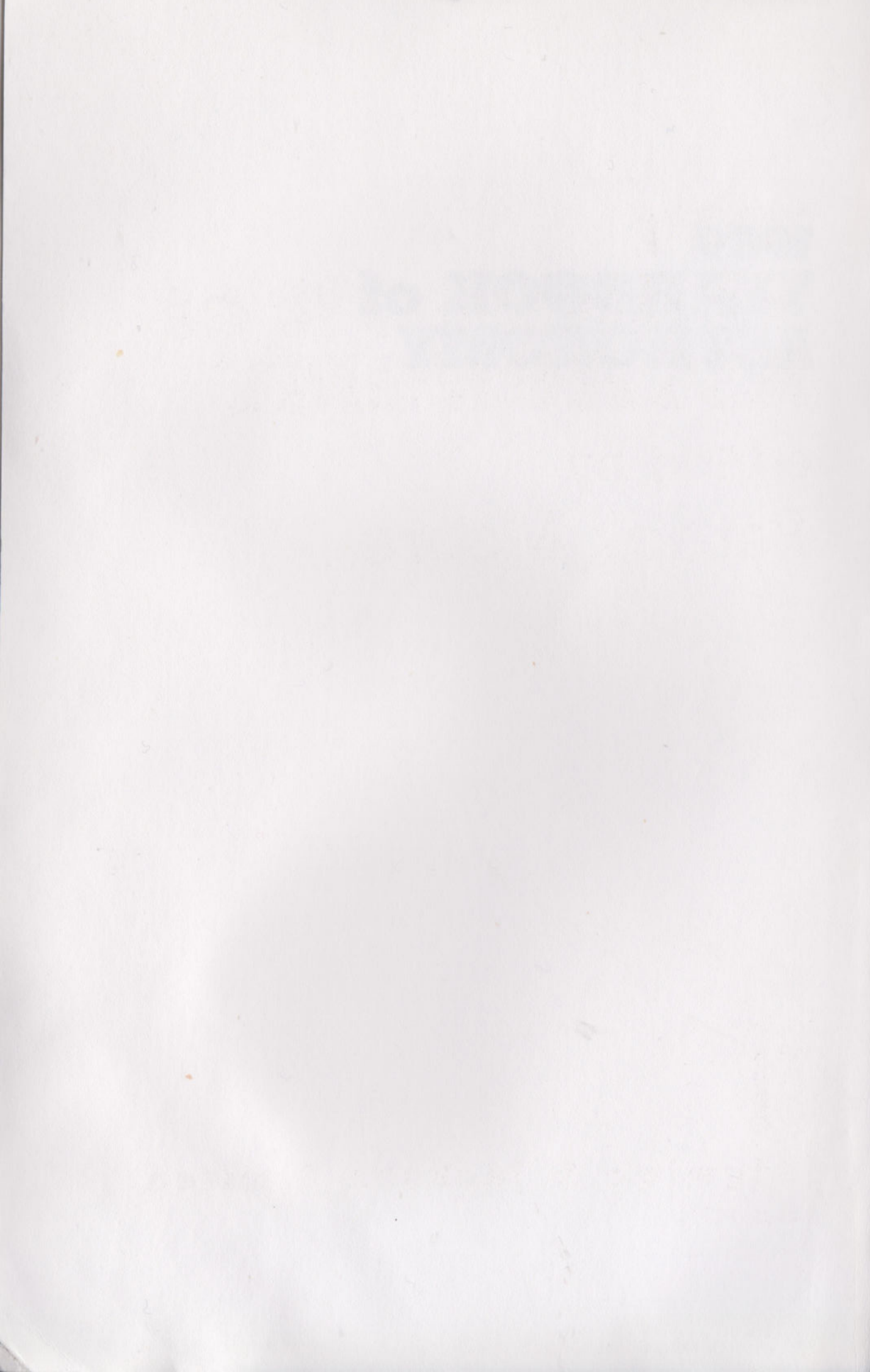
1989 Yearbook of Astronomy

**Edited by
Patrick Moore**



**a SIDGWICK
SOFTBACK**
Original

1989
YEARBOOK of
ASTRONOMY



1989
YEARBOOK of
ASTRONOMY

edited by

Patrick Moore



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Editor's Foreword

For this 1989 edition of the Yearbook we have made one change to the previous plan. Many readers have written asking for an extension of the sections dealing with variable stars, inasmuch as variable star observation is an ever-increasing pastime among amateur astronomers. We have therefore given a more extended list, with co-ordinates updated for epoch 2000, and given dates of the maxima of long-period and semi-regular stars, with the full knowledge that, because of the changes from one cycle to another, these dates may be no more than approximate.

Our contributors include some who are known to all *Yearbook* readers – no issue would be complete without an article from Dr David Allen, and other 'regulars' include Dr Paul Murdin and Dr Peter Cattermole. Professor Arnold Wolfendale follows up his earlier article on gamma-ray astronomy, while Dr Gilbert Fielder returns to the subject of our nearest neighbour, the Moon. We welcome, for the first time, Dr Ian McLean, who describes the invention of a revolutionary infra-red camera, and Kieron Leech, who describes objects thousands of millions of light-years from us. And as always, the monthly notes are entirely the work of Gordon Taylor of the Royal Greenwich Observatory.

We hope that you will find this issue useful.

PATRICK MOORE

Selsey, July 1988

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets and give details of other astronomical phenomena visible in both the northern and southern hemispheres. Two sets of the star charts are provided. The **Northern Charts** (pp. 14 to 39) are designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude. The **Southern Charts** (pp. 40 to 65) are drawn for latitude 35 degrees south, and are suitable for use in South Africa, Australia and New Zealand, and other stations in approximately the same south latitude. The reader who needs more detailed information will find *Norton's Star Atlas* (Longman) an invaluable guide, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers, and periodic comets may be found in the *Handbook* of the British Astronomical Association. The new British monthly periodical, with current news, articles, and monthly notes is *Astronomy Now*. Readers will also find details of forthcoming events given in the *American Sky and Telescope*. This monthly publication also produces a special occultation supplement giving predictions for the United States and Canada.

Important Note

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. All the dates, and the times of a few events (e.g. eclipses), are given in Greenwich Mean Time (G.M.T.), which is related to local time by the formula

Local Mean Time = G.M.T. – west longitude

In practice, small differences of longitudes are ignored, and the observer will use local clock time, which will be the appropriate

Standard (or Zone) Time. As the formula indicates, places in west longitude will have a Standard Time slow on G.M.T., while places in east longitude will have a Standard Time fast on G.M.T. as examples we have:

Standard Time in

New Zealand	G.M.T. + 12 hours
Victoria; N.S.W.	G.M.T. + 10 hours
Western Australia	G.M.T. + 8 hours
South Africa	G.M.T. + 2 hours
British Isles	G.M.T.
Eastern S.T.	G.M.T. - 5 hours
Central S.T.	G.M.T. - 6 hours, etc

If Summer Time is in use, the clocks will have to have been advanced by one hour, and this hour must be subtracted from the clock time to give Standard Time.

In Great Britain and N. Ireland, Summer Time will be in force in 1989 from March 26^d01^h until October 29^d01^h G.M.T.

Notes on the Star Charts

The stars, together with the Sun, Moon and planets seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

The two sets of star charts are similar in design. At each opening there is a group of four charts which give a complete coverage of the sky up to an altitude of $62\frac{1}{2}$ degrees; there are twelve such groups to cover the entire year. In the **Northern Charts** (for 52 degrees north) the upper two charts show the southern sky, south being at the centre and east on the left. The coverage is from 10 degrees north of east (top left) to 10 degrees north of west (top right). The two lower charts show the northern sky from 10 degrees south of west (lower left) to 10 degrees south of east (lower right). There is thus an overlap east and west.

Conversely, in the **Southern Charts** (for 35 degrees south) the

upper two charts show the northern sky, with north at the centre and east on the right. The two lower charts show the southern sky, with south at the centre and east on the left. The coverage and overlap is the same on both sets of charts.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, and this amounts to two hours in a month. Hence the twelve groups of charts in each set are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. Each group is numbered in bold type, and the number to be used for any given month and time is summarized in the following table:

<i>Local Time</i>	18h	20h	22h	0h	2h	4h	6h
January	11	12	1	2	3	4	5
February	12	1	2	3	4	5	6
March	1	2	3	4	5	6	7
April	2	3	4	5	6	7	8
May	3	4	5	6	7	8	9
June	4	5	6	7	8	9	10
July	5	6	7	8	9	10	11
August	6	7	8	9	10	11	12
September	7	8	9	10	11	12	1
October	8	9	10	11	12	1	2
November	9	10	11	12	1	2	3
December	10	11	12	1	2	3	4

The charts are drawn to scale, the horizontal measurements, marked at every 10 degrees, giving the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to $62\frac{1}{2}$ degrees. Estimates of altitude and azimuth made from these charts will necessarily be mere approximations, since no observer will be exactly at the adopted latitude, or at the stated time, but they will serve for the identification of stars and planets.

The ecliptic is drawn as a broken line on which longitude is marked at every 10 degrees; the positions of the planets are then

easily found by reference to the table on page 72. It will be noticed that on the Southern Charts the **ecliptic** may reach an altitude in excess of $62\frac{1}{2}$ degrees on star charts 5 to 9. The continuations of the broken line will be found on the charts of overhead stars.

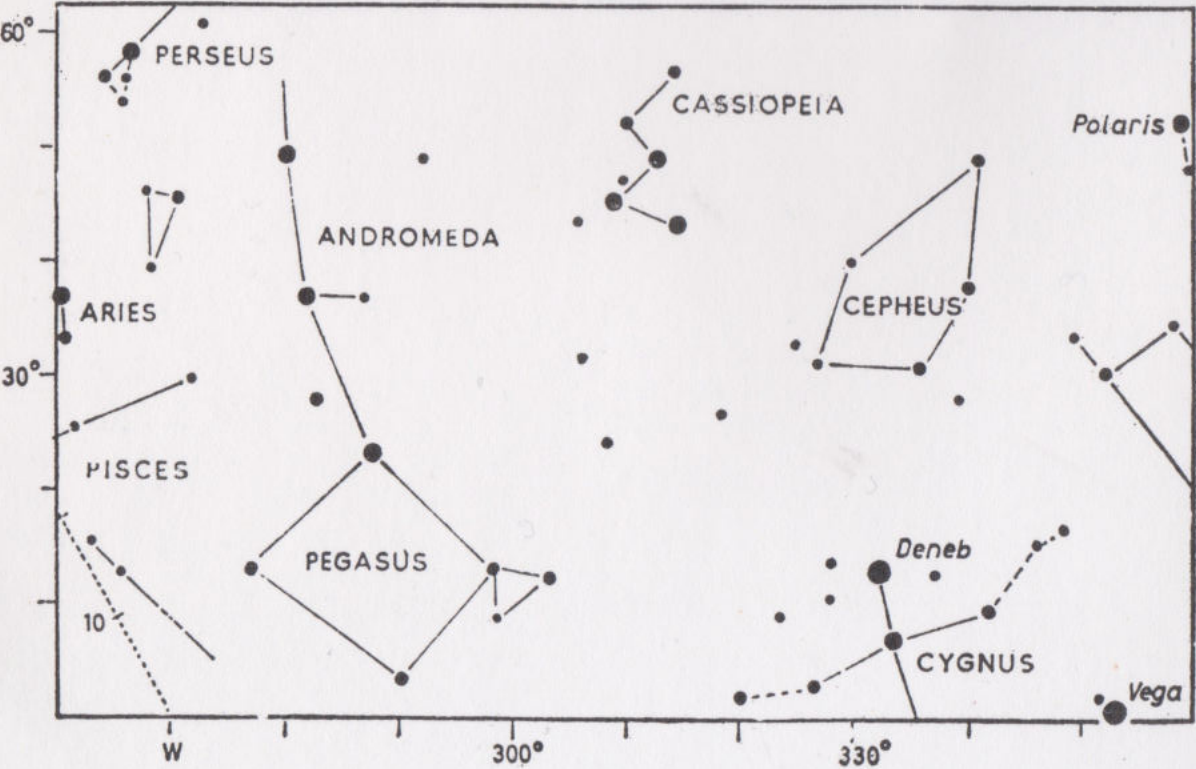
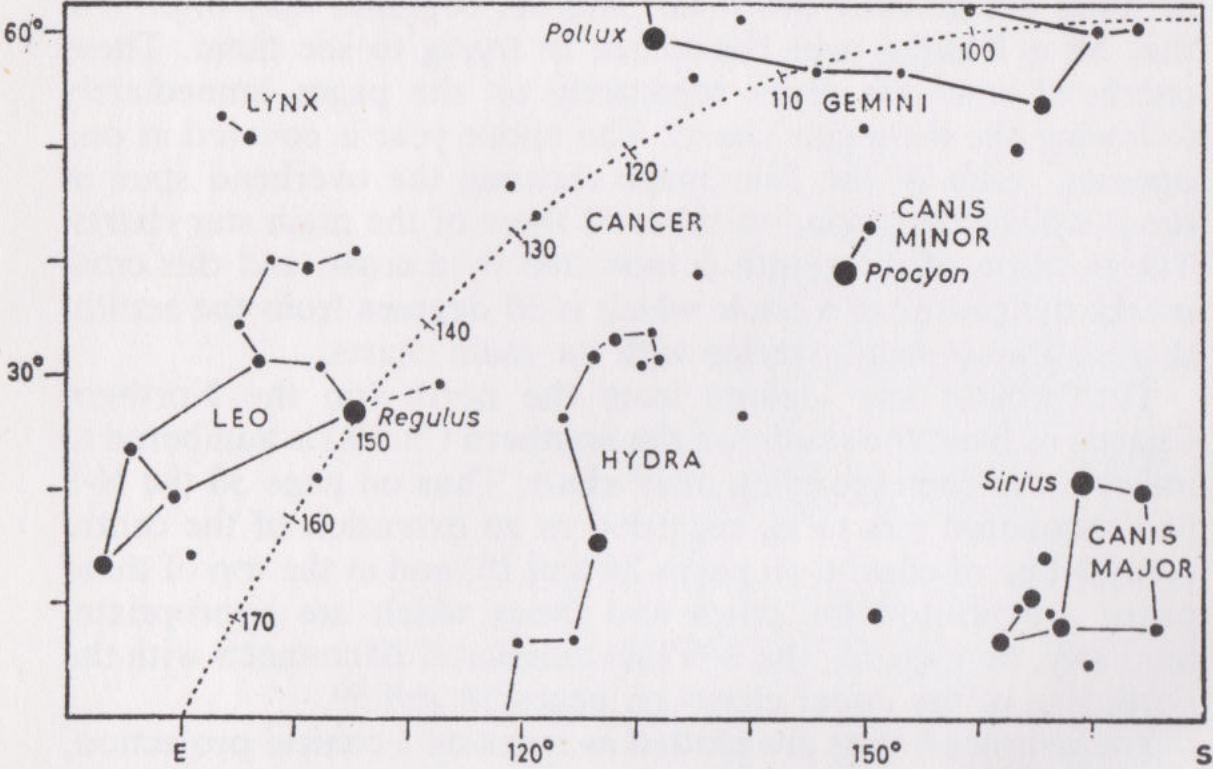
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These overhead stars are given separately on the pages immediately following the main star charts. The entire year is covered at one opening, each of the four maps showing the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith is indicated by a cross, and this cross marks the centre of a circle which is 35 degrees from the zenith; there is thus a small overlap with the main charts.

The broken line leading from the north (on the Northern Charts) or from the south (on the Southern Charts) is numbered to indicate the corresponding main chart. Thus on page 38 the N-S line numbered 6 is to be regarded as an extension of the centre (south) line of chart 6 on pages 24 and 25, and at the top of these pages are printed the dates and times which are appropriate. Similarly, on page 65, the S-N line numbered 10 connects with the north line of the upper charts on pages 58 and 59.

The overhead stars are plotted as maps on a conical projection, and the scale is rather smaller than that of the main charts.

1L

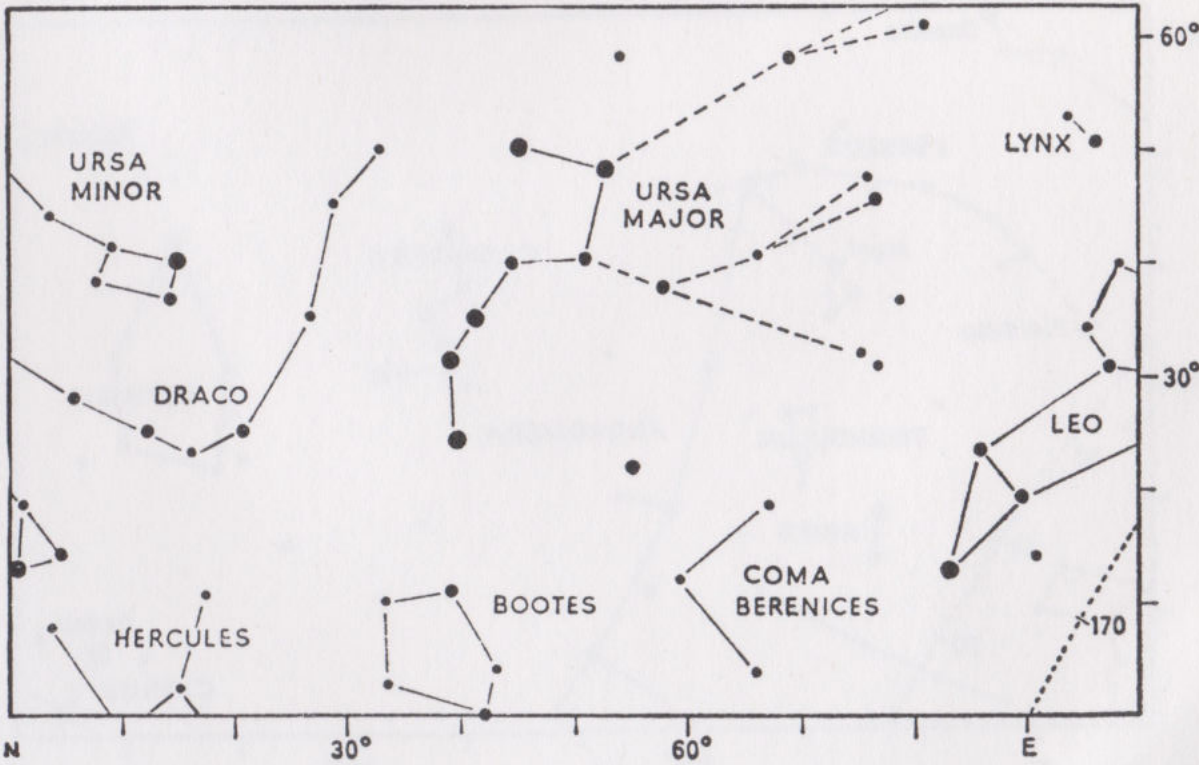
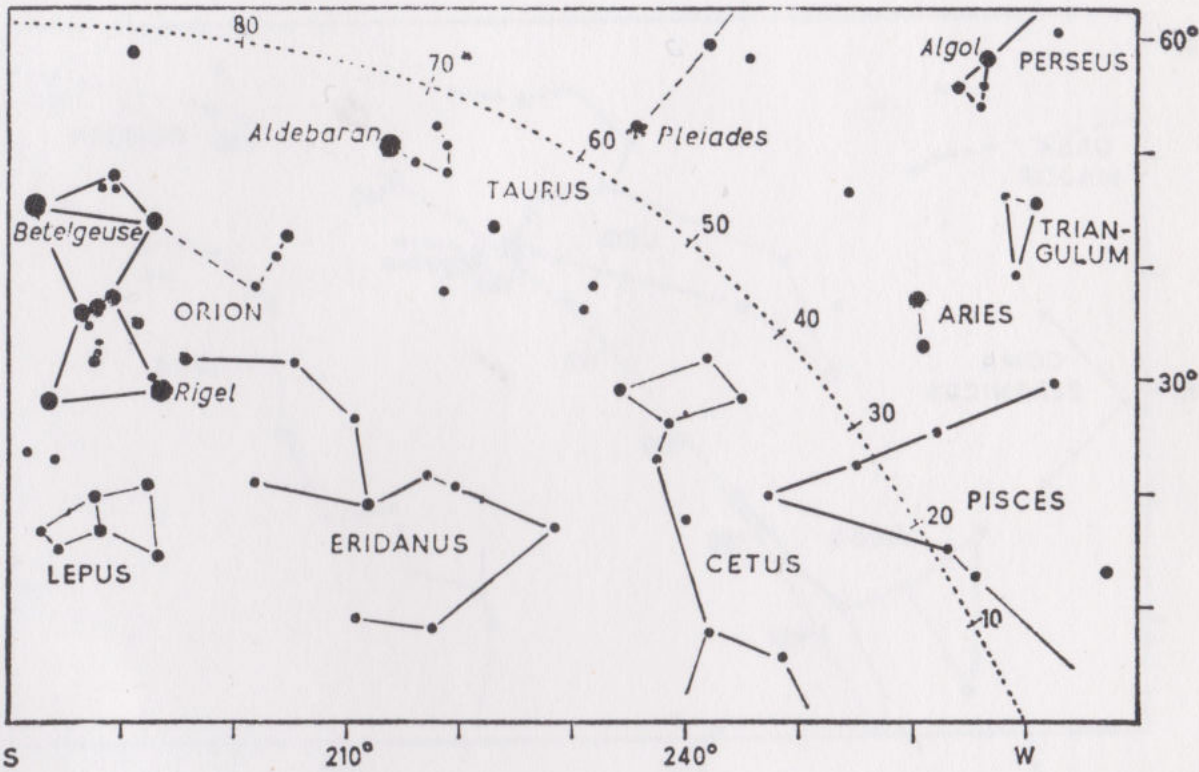
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November 6 at 3 ^h	November 21 at 2 ^h
December 6 at 1 ^h	December 21 at midnight
January 6 at 23 ^h	January 21 at 22 ^h
February 6 at 21 ^h	February 21 at 20 ^h



October 6 at 5^h
November 6 at 3^h
December 6 at 1^h
January 6 at 23^h
February 6 at 21^h

October 21 at 4^h
November 21 at 2^h
December 21 at midnight
January 21 at 22^h
February 21 at 20^h

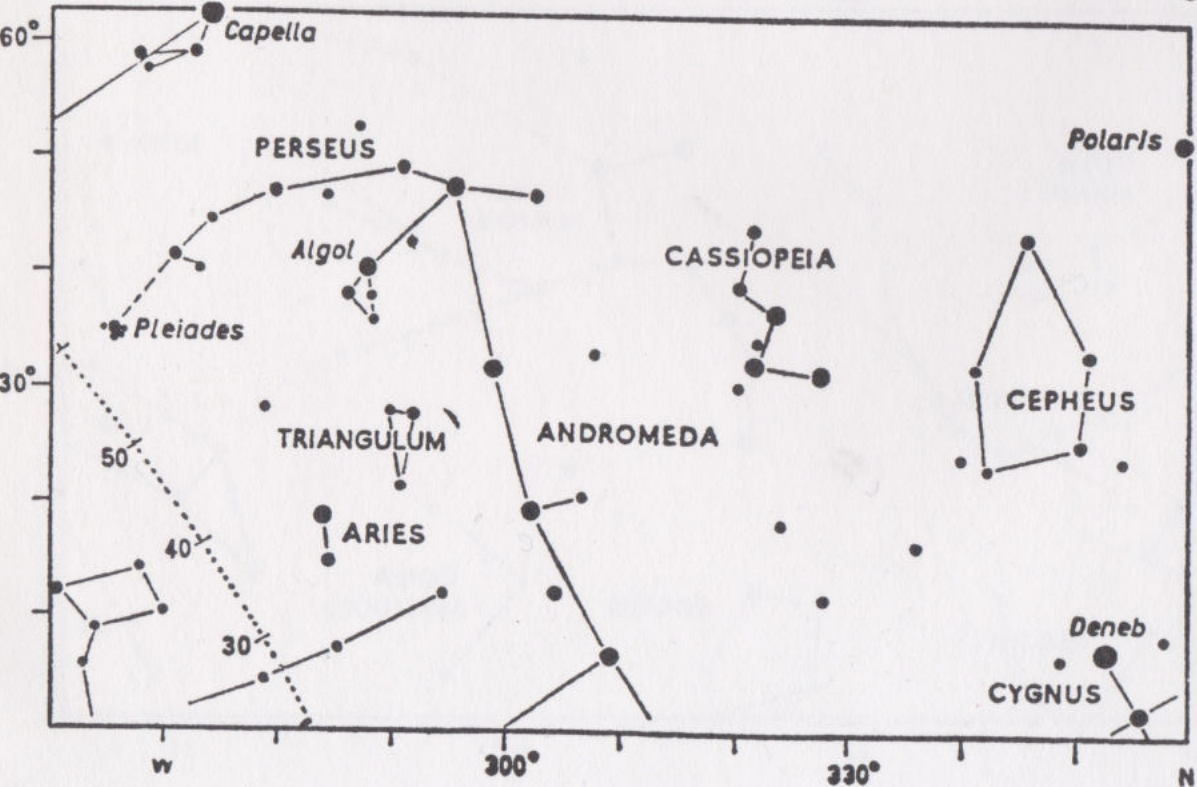
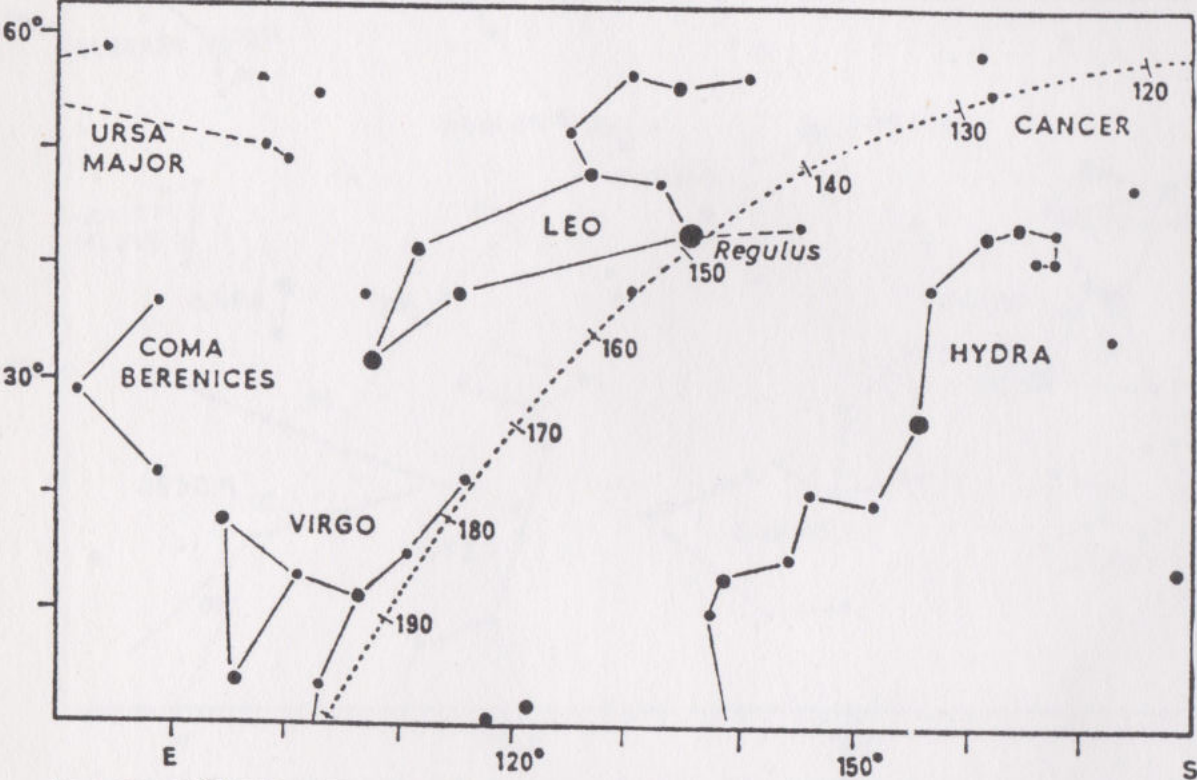
1R



2L

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March 6 at 21^h

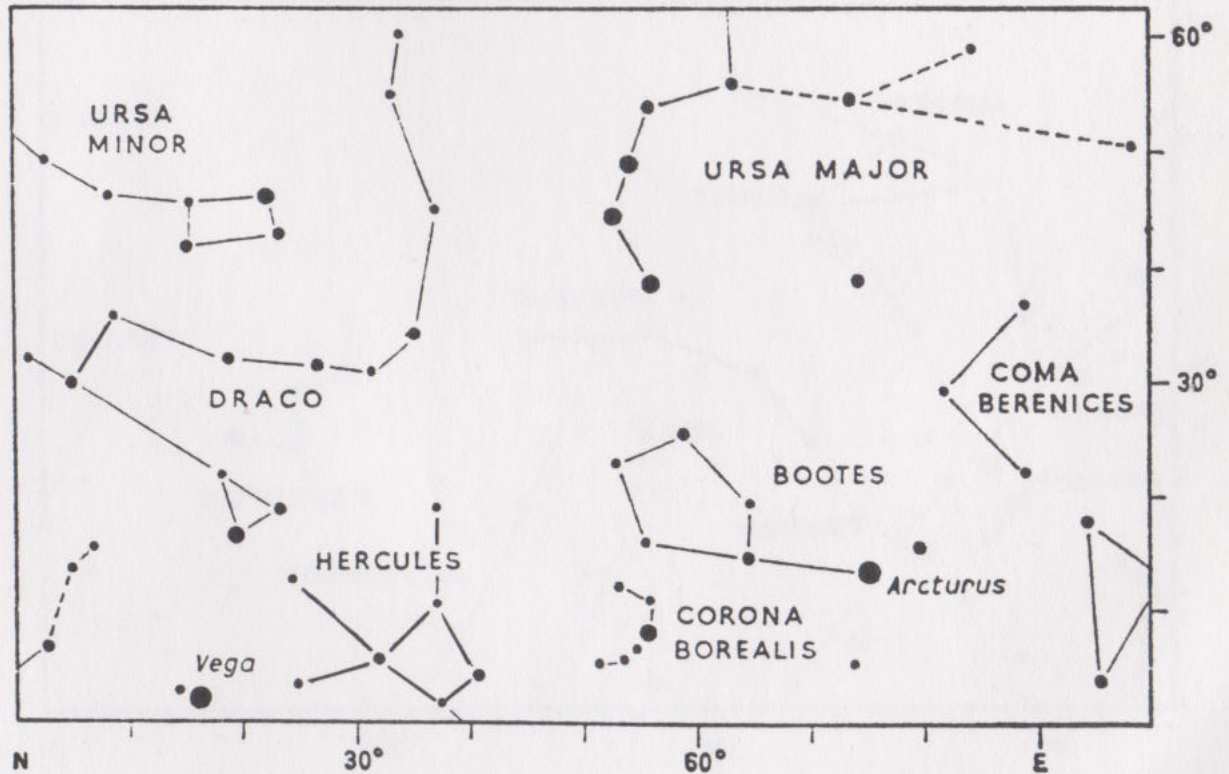
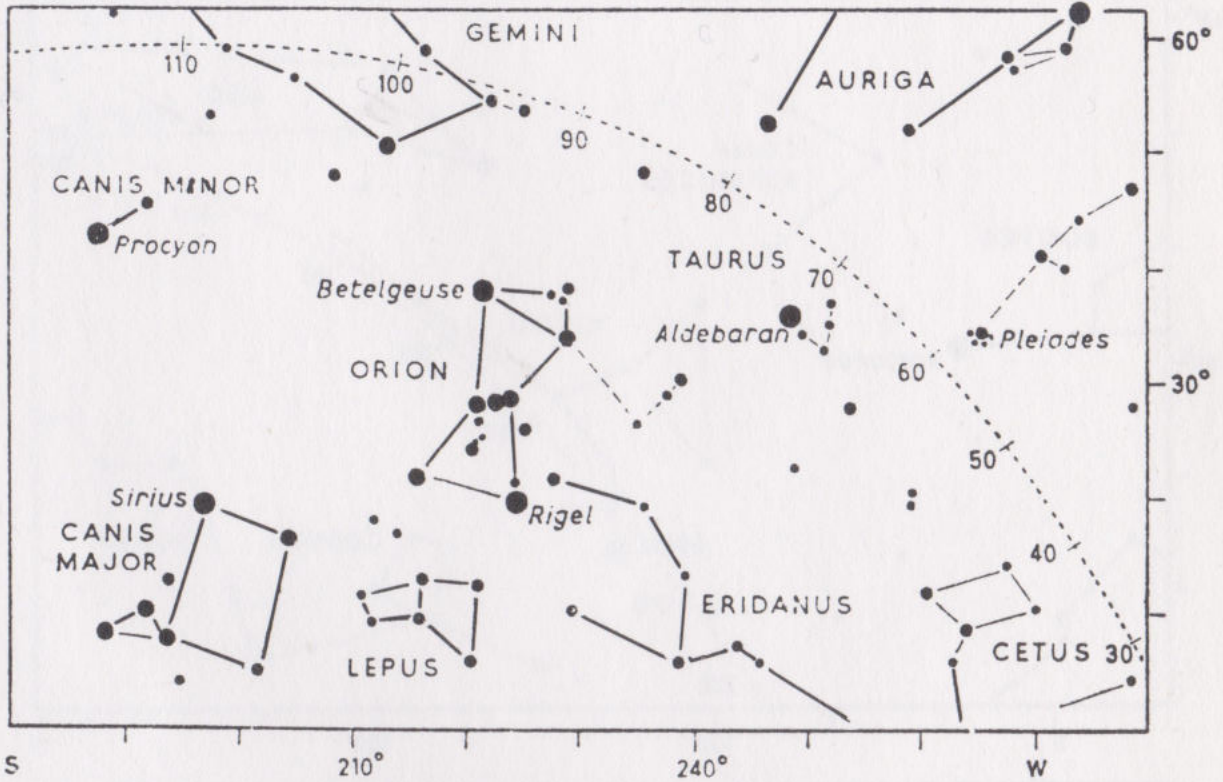
November 21 at 4^h
December 21 at 2^h
January 21 at midnight
February 21 at 22^h
March 21 at 20^h



November 6 at 5^h
 December 6 at 3^h
 January 6 at 1^h
 February 6 at 23^h
 March 6 at 21^h

November 21 at 4^h
 December 21 at 2^h
 January 21 at midnight
 February 21 at 22^h
 March 21 at 20^h

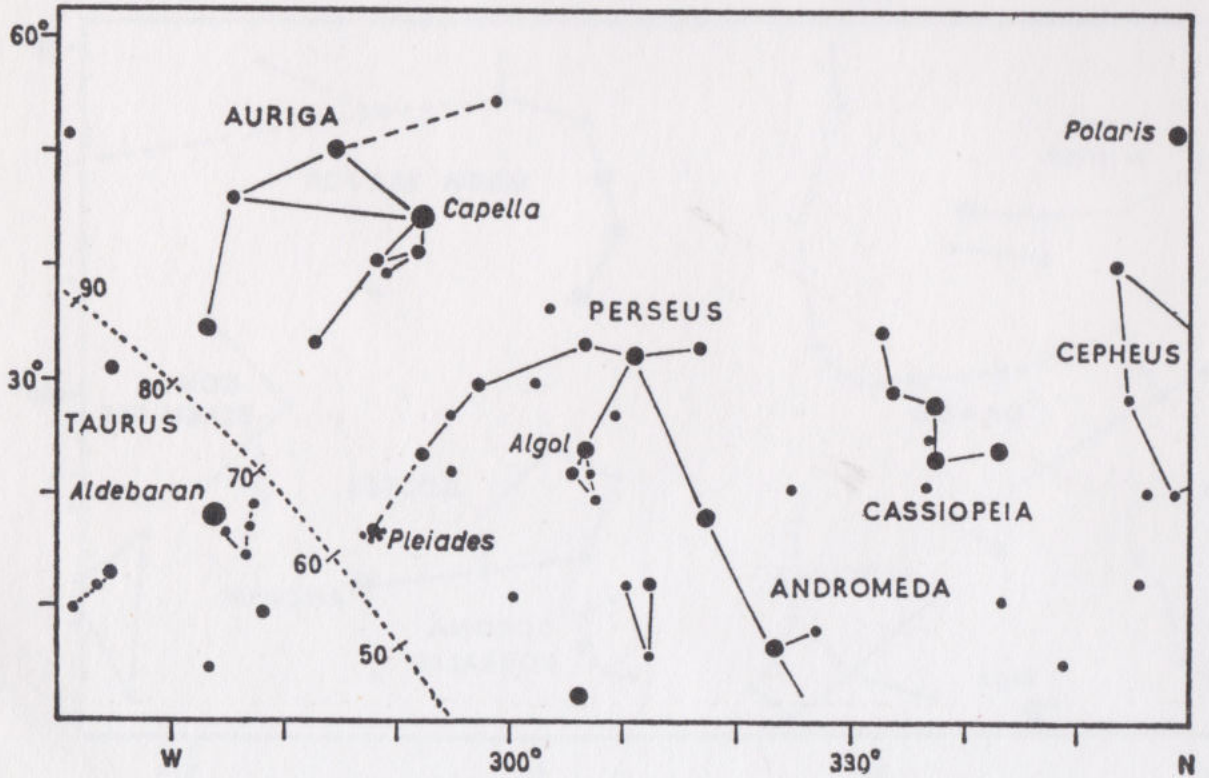
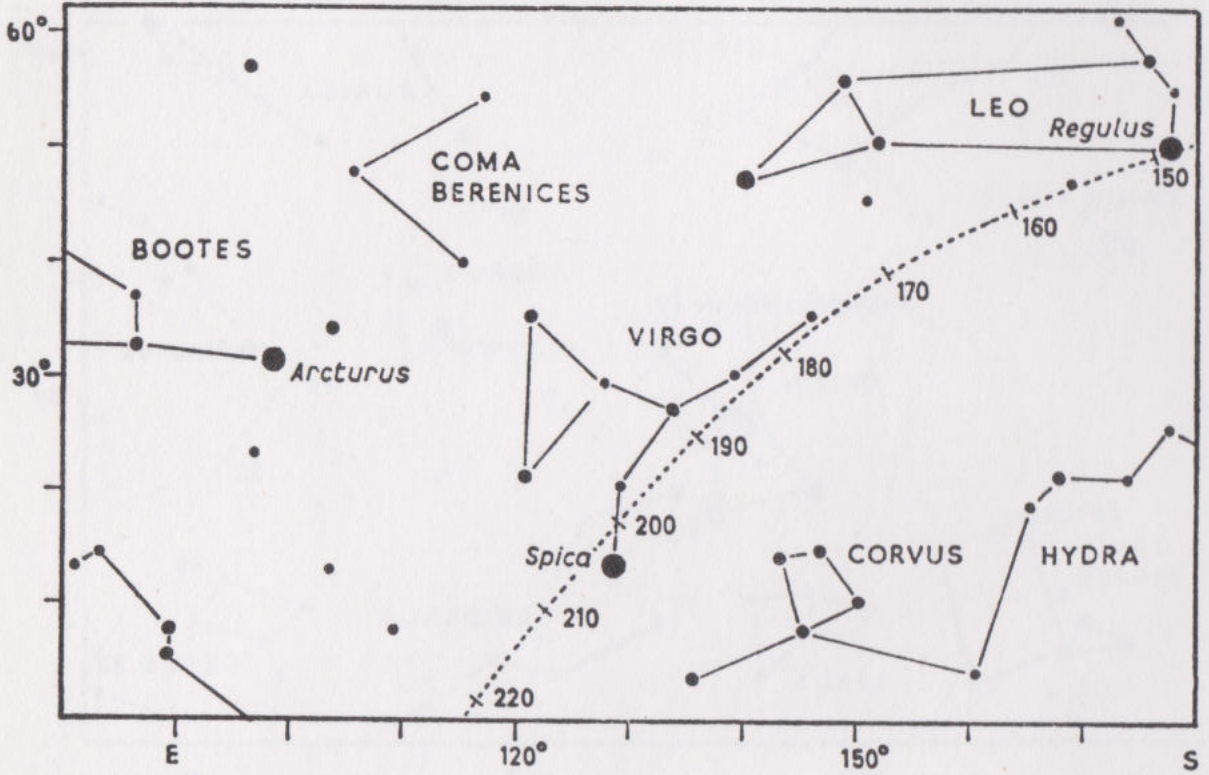
2R



3L

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 January 6 at 3^h
 February 6 at 1^h
 March 6 at 23^h
 April 6 at 21^h

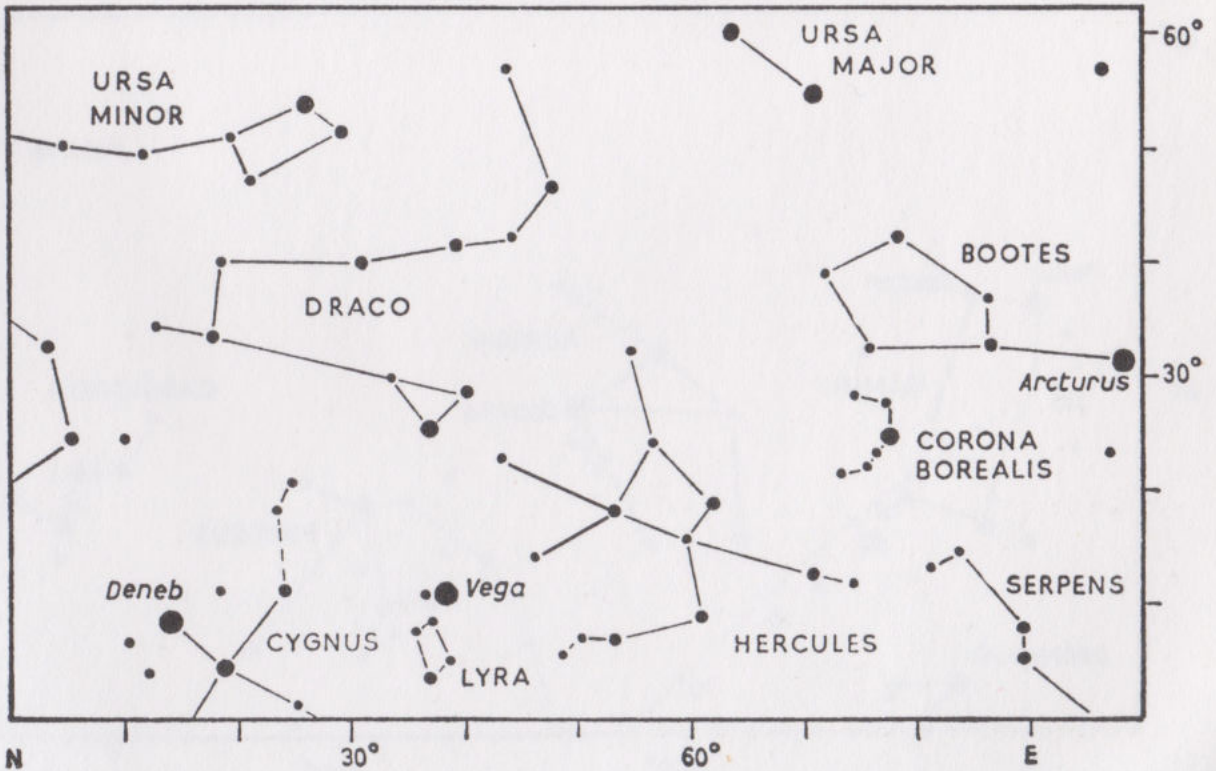
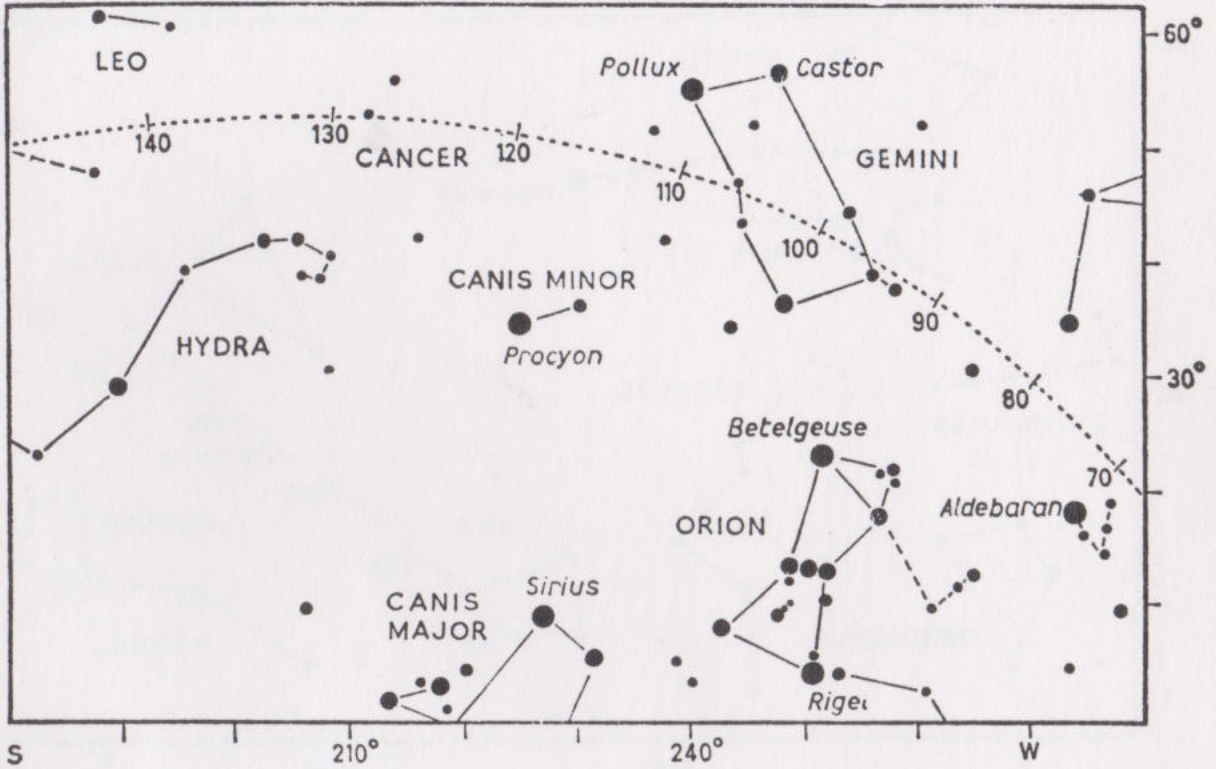
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 February 21 at midnight
 March 21 at 22^h
 April 21 at 20^h



December 6 at 5^h
 January 6 at 3^h
 February 6 at 1^h
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 April 6 at 21^h

December 21 at 4^h
 January 21 at 2^h
 February 21 at midnight
 March 21 at 22^h
 April 21 at 20^h

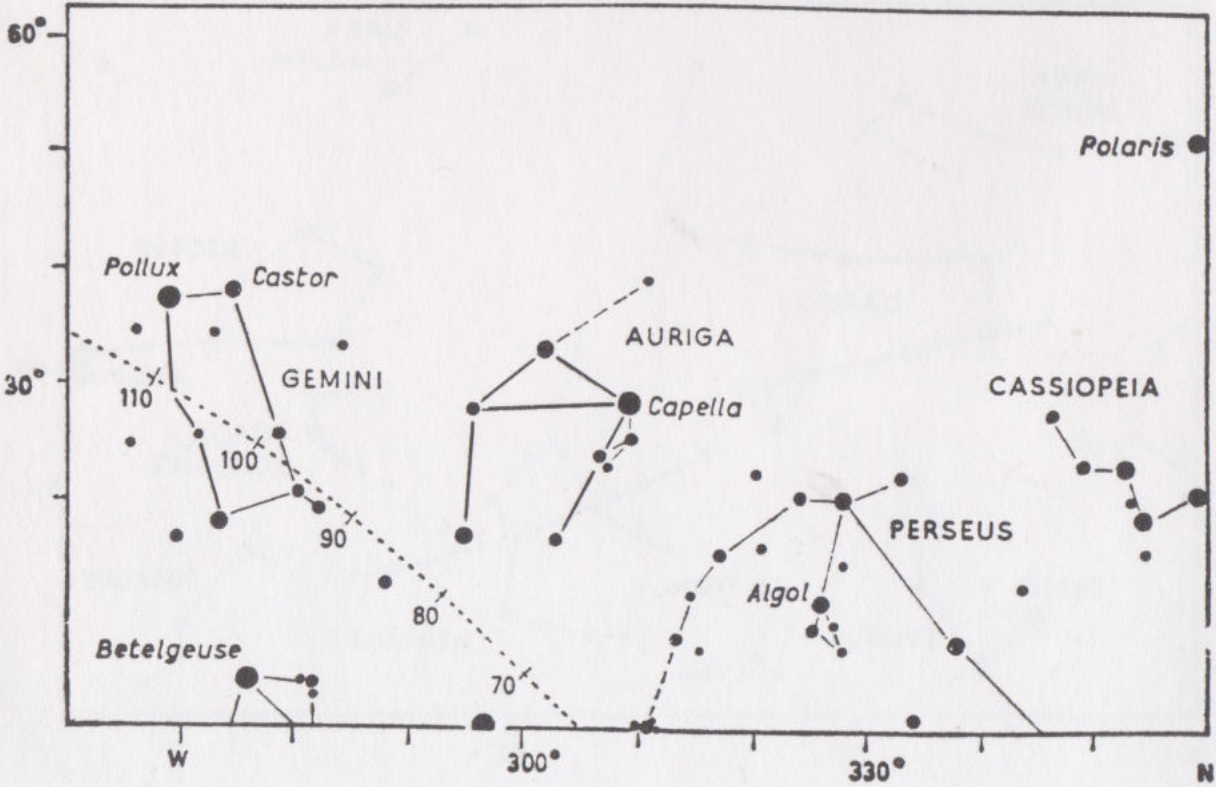
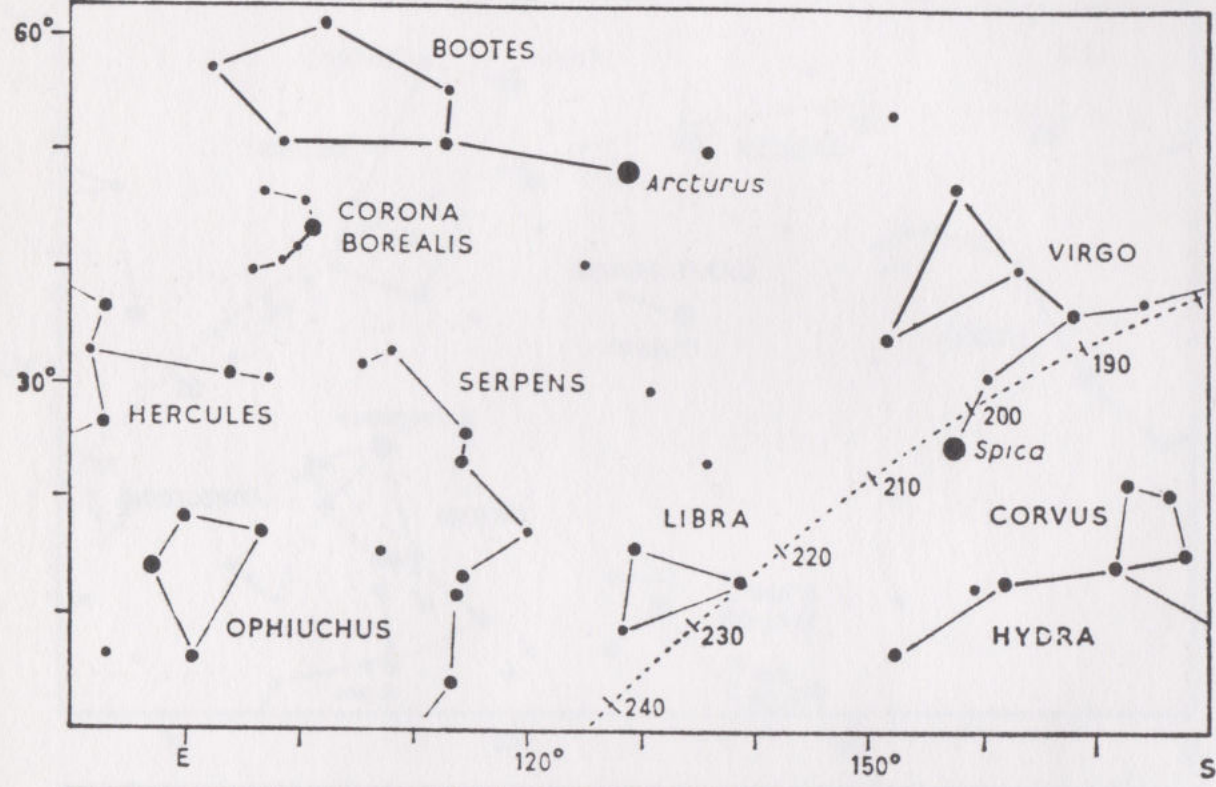
3R



4L

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March 6 at 1^h
April 6 at 23^h
May 6 at 21^h

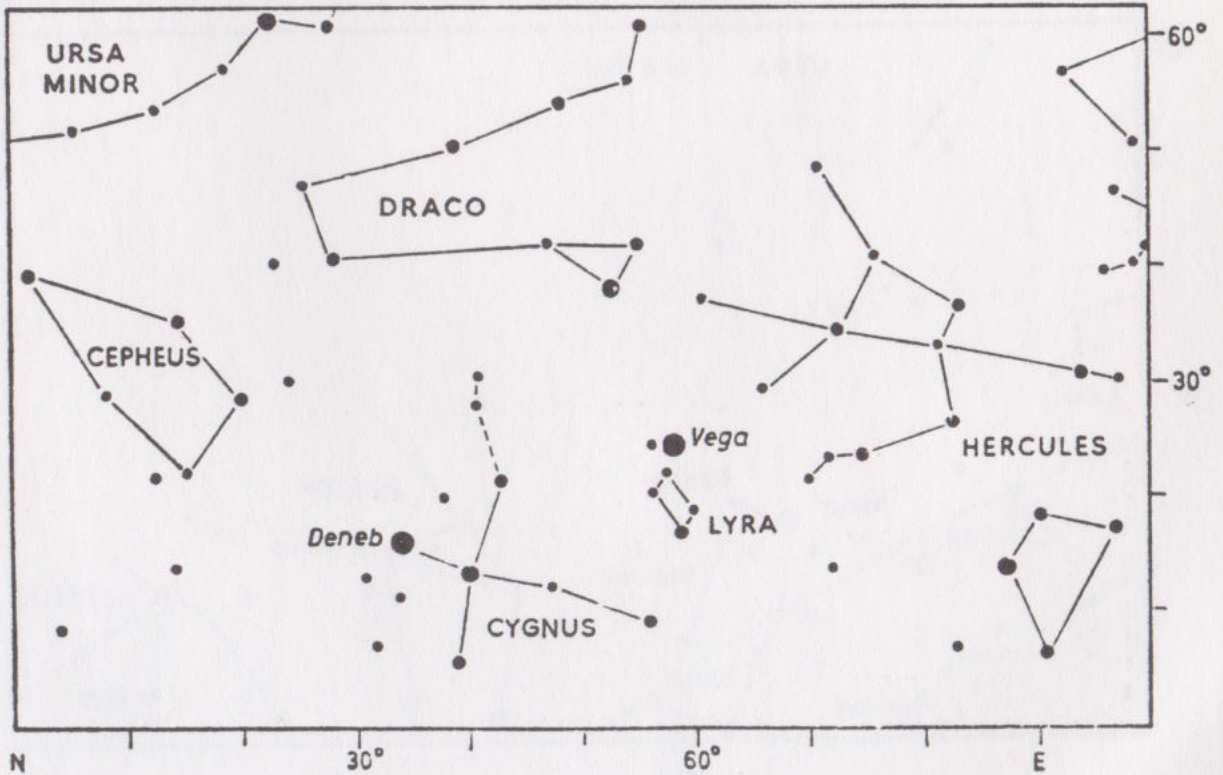
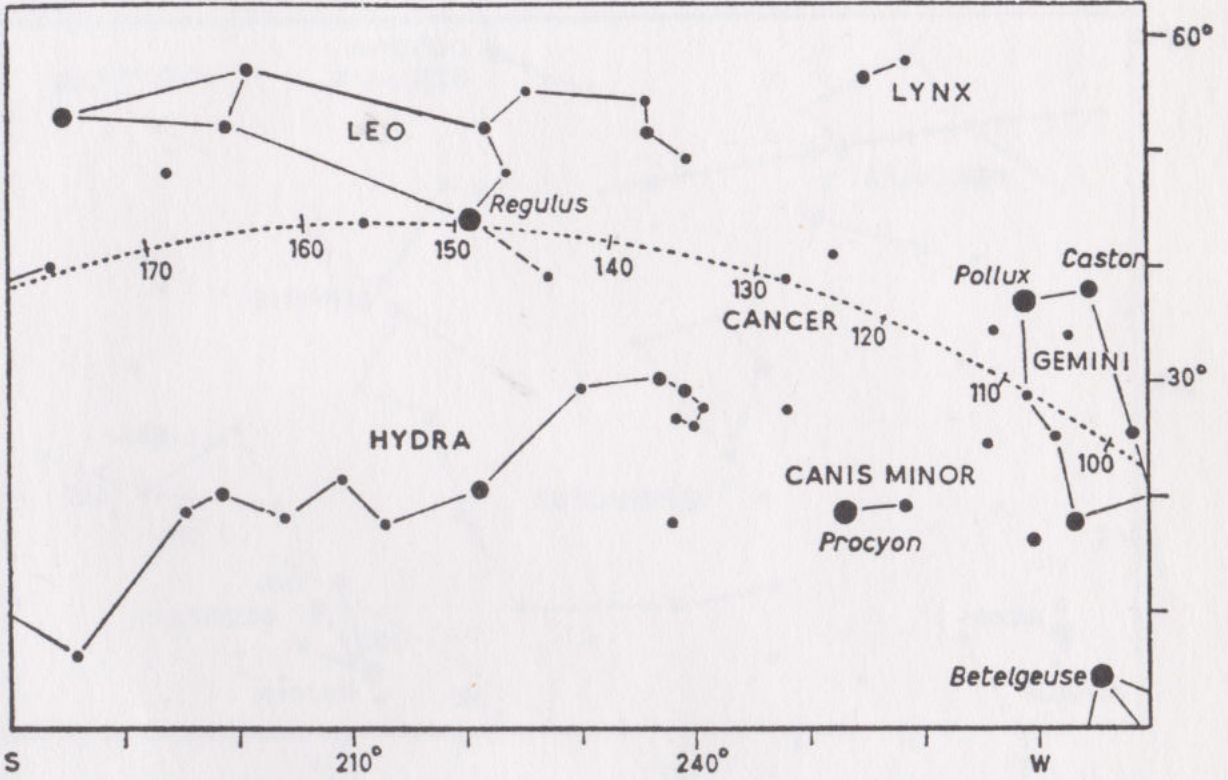
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February 21 at 2^h
March 21 at midnight
April 21 at 22^h
May 21 at 20^h



January 6 at 5^h
 February 6 at 3^h
 March 6 at 1^h
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 May 6 at 21^h

January 21 at 4^h
 February 21 at 2^h
 March 21 at midnight
 April 21 at 22^h
 May 21 at 20^h

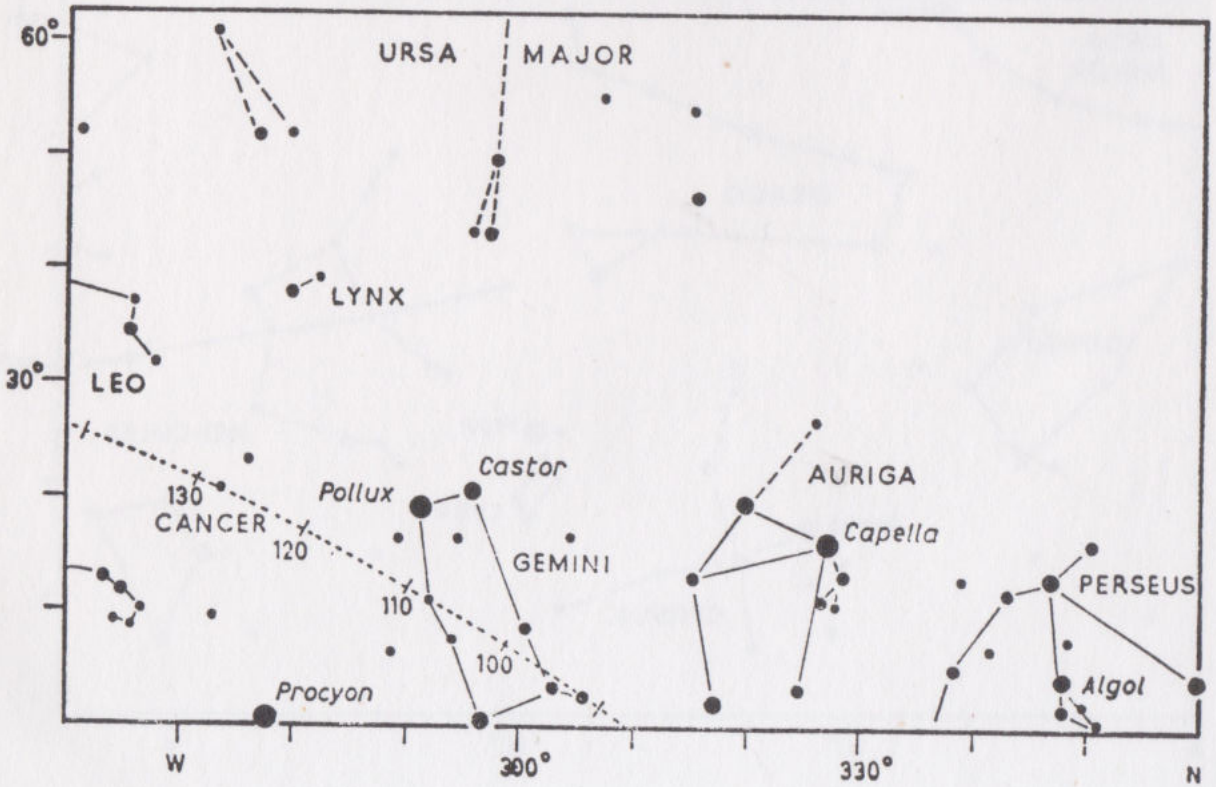
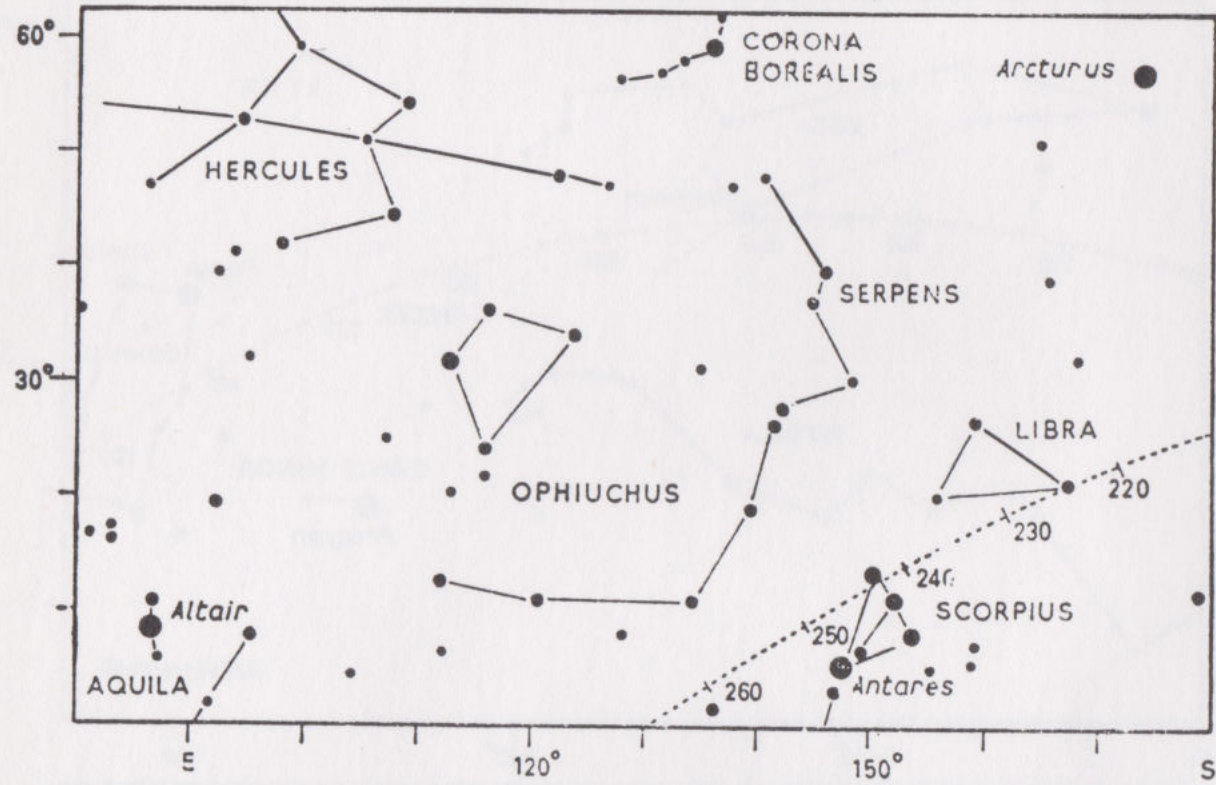
4R



5L

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April 6 at 1^h
May 6 at 23^h

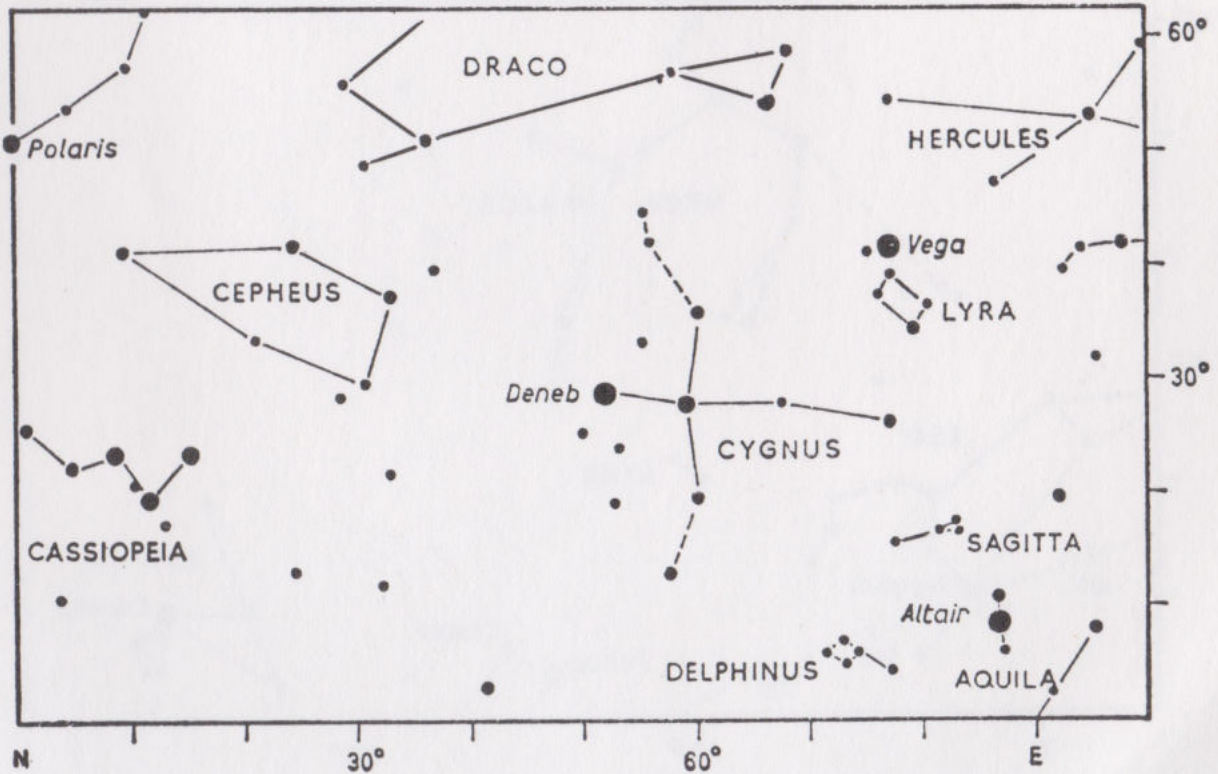
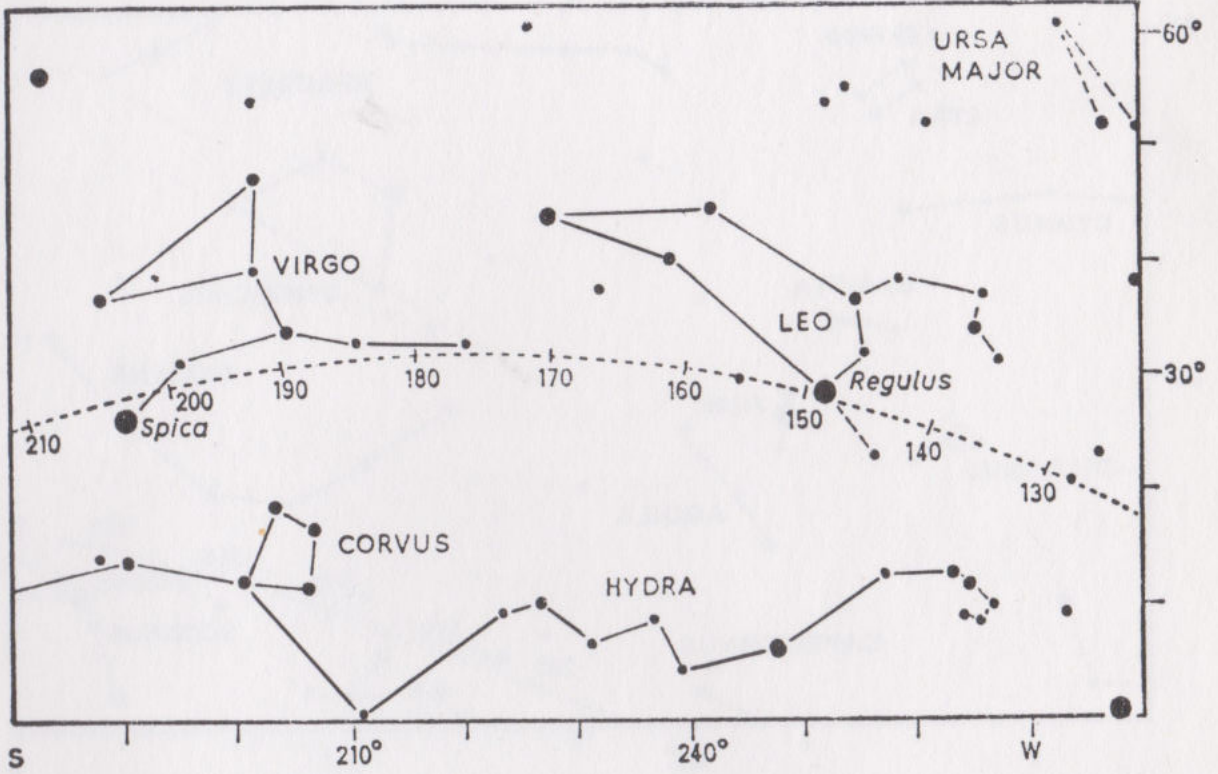
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March 21 at 2^h
April 21 at midnight
May 21 at 22^h



January 6 at 7^h
 February 6 at 5^h
 March 6 at 3^h
 April 6 at 1^h
 May 6 at 23^h

January 21 at 6^h
 February 21 at 4^h
 March 21 at 2^h
 April 21 at midnight
 May 21 at 22^h

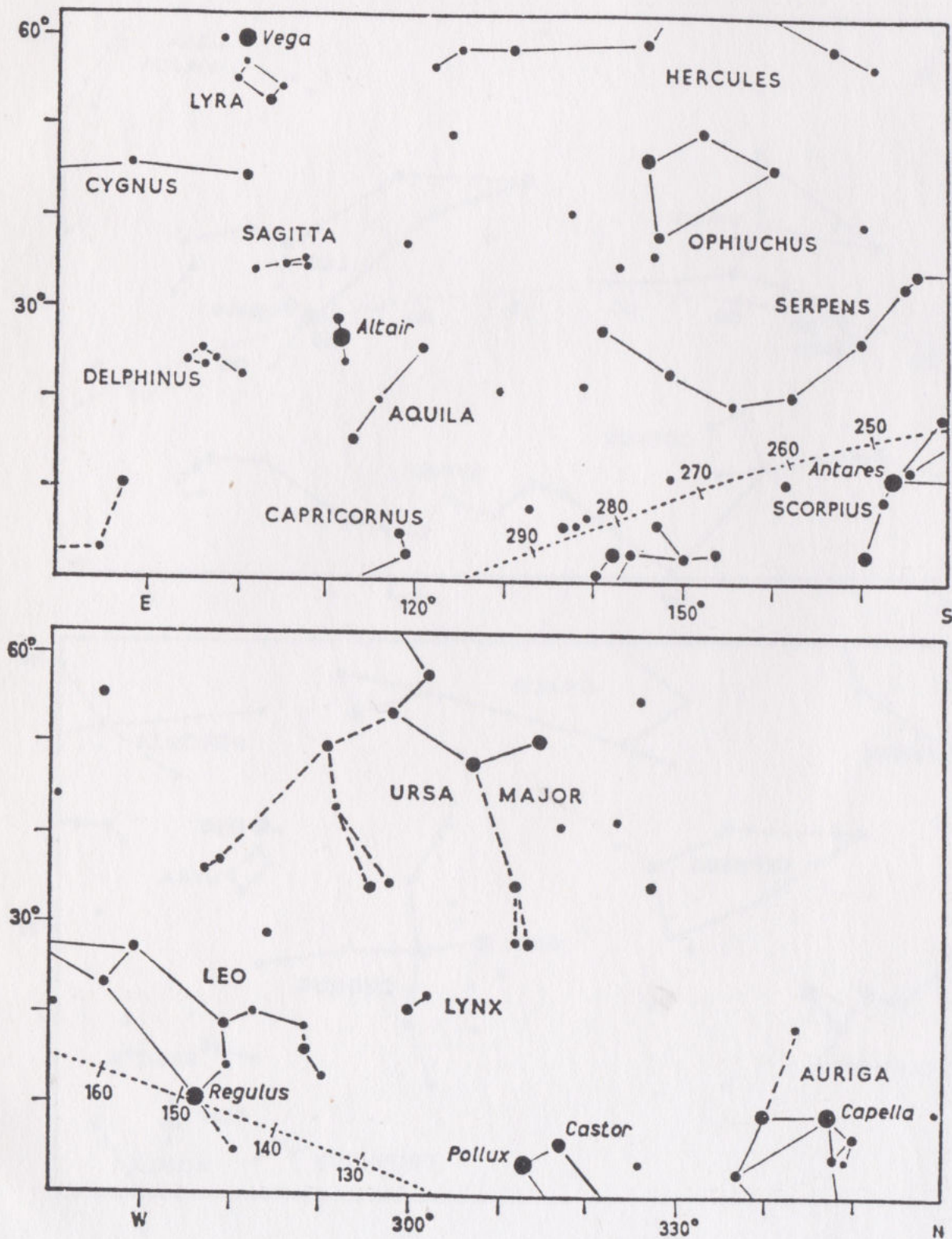
5R



6L

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 April 6 at 3^h
 May 6 at 1^h
 June 6 at 23^h
 July 6 at 21^h

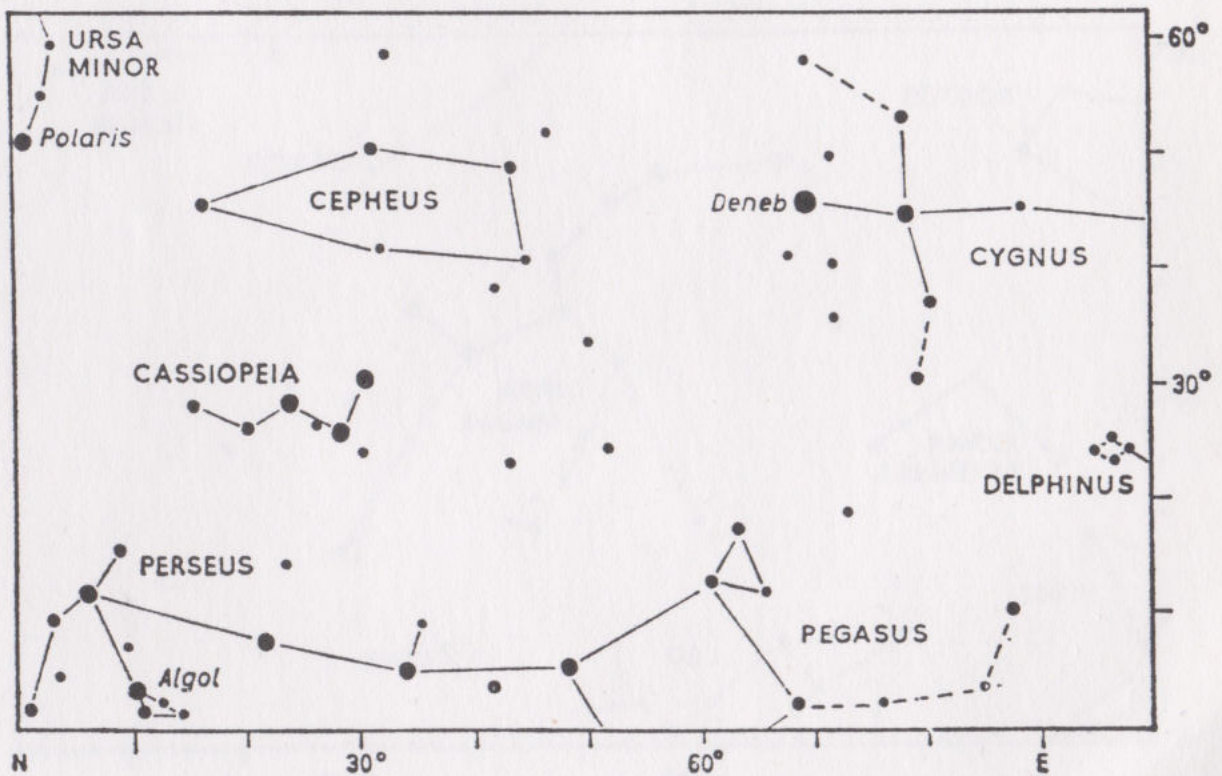
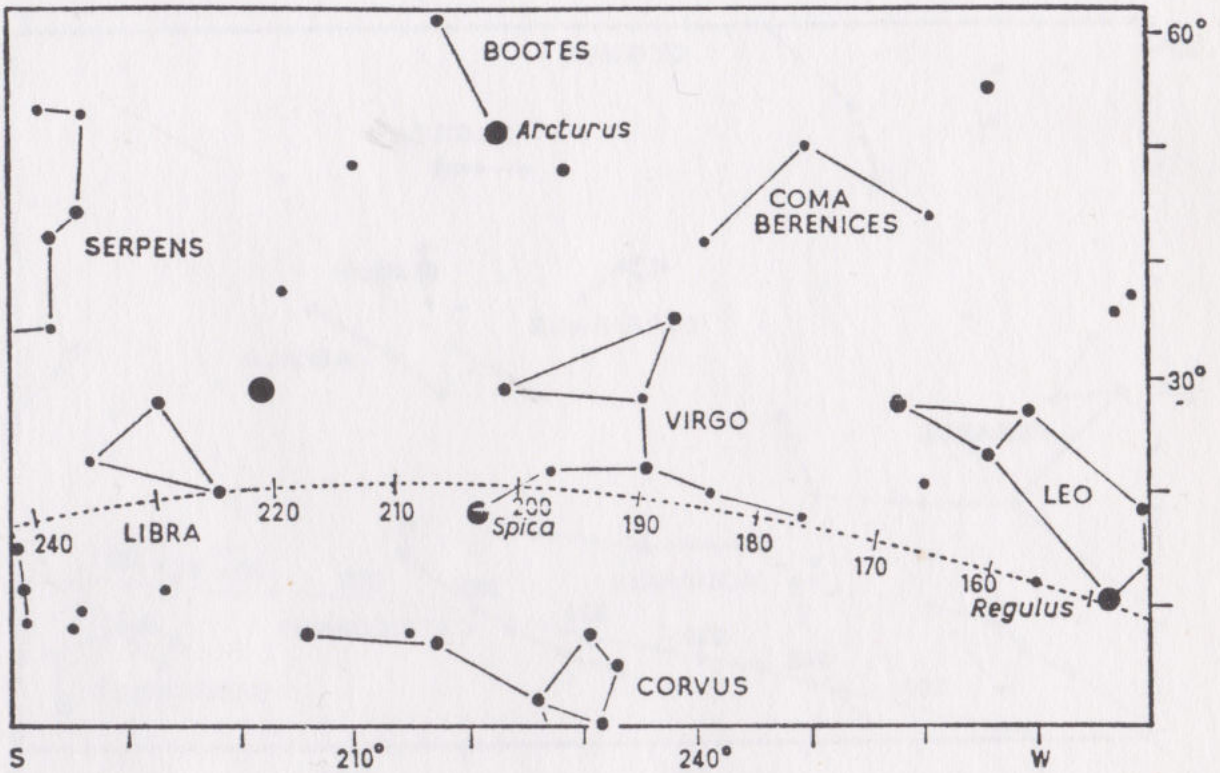
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 June 21 at 22^h
 July 21 at 20^h



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 June 6 at 23^h
 July 6 at 21^h

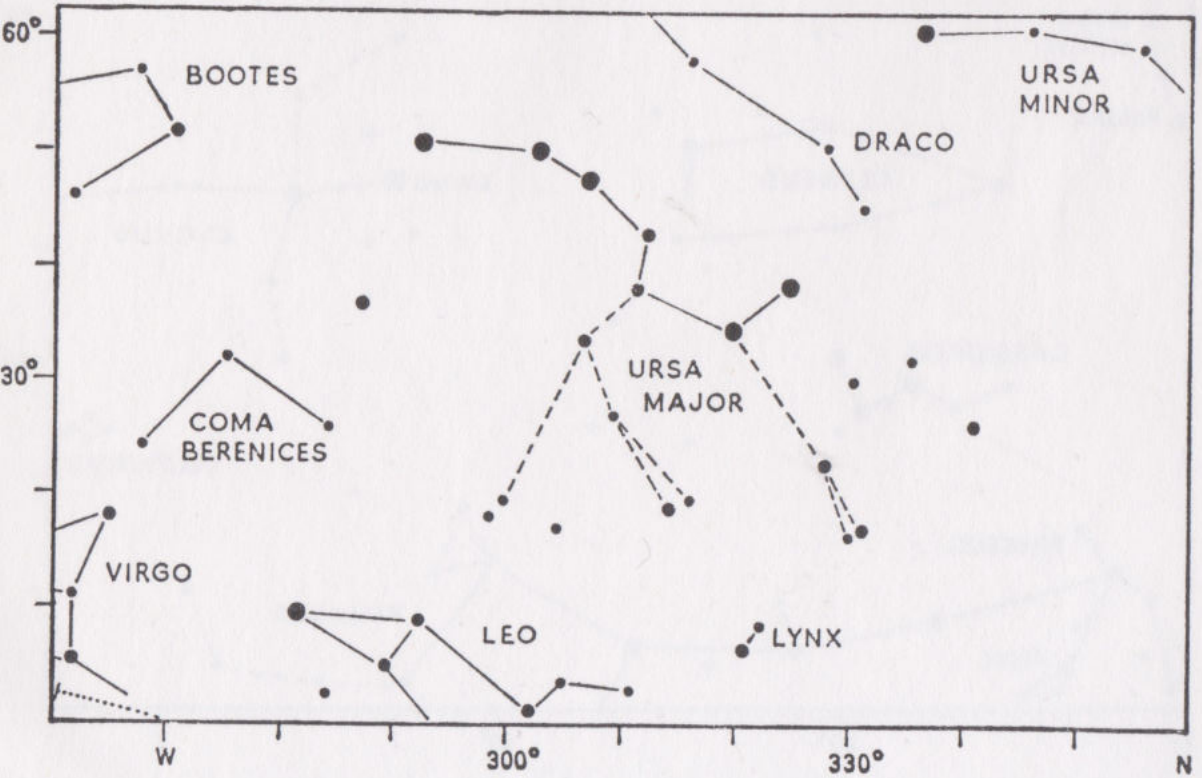
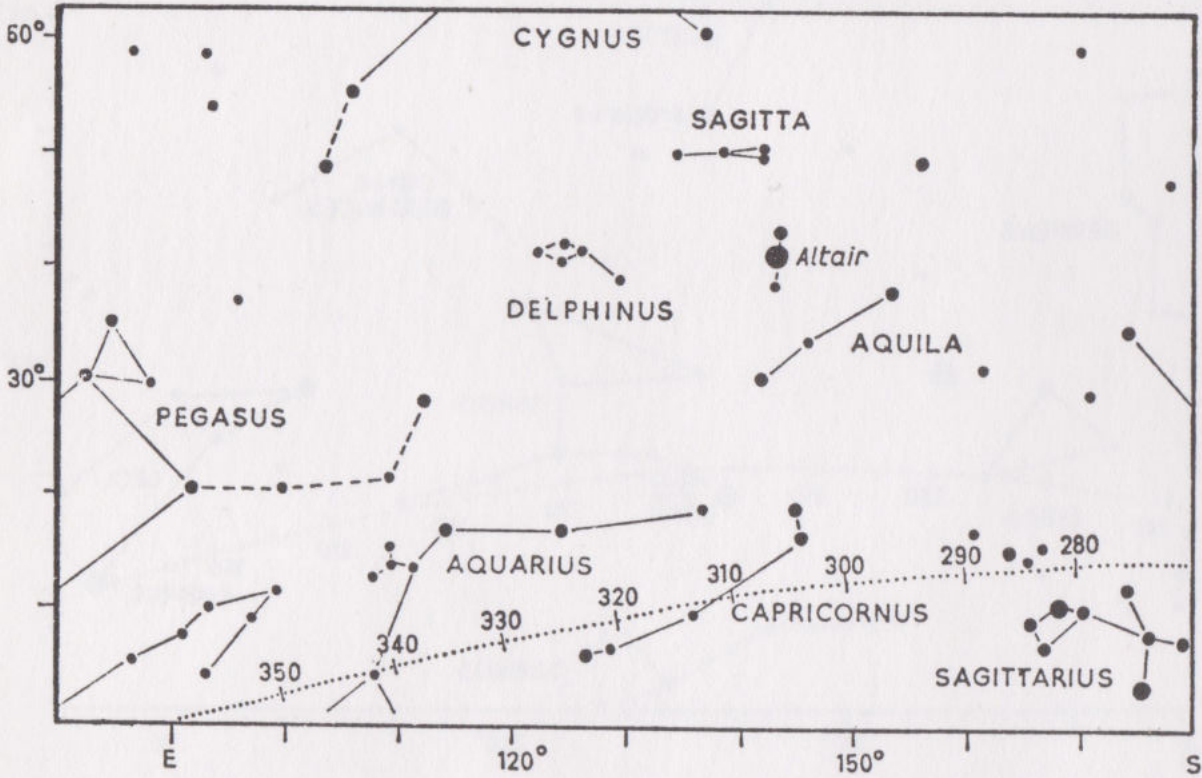
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 May 21 at midnight
 June 21 at 22ⁿ
 July 21 at 20^h

6R



7L

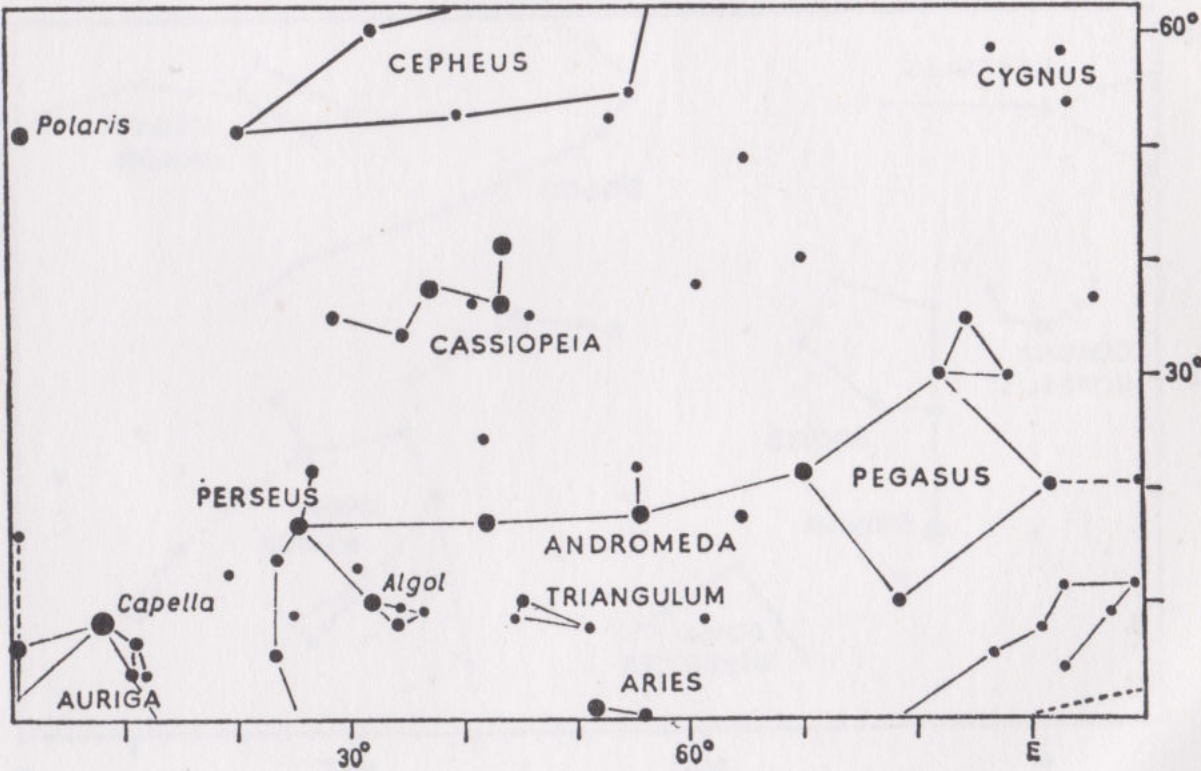
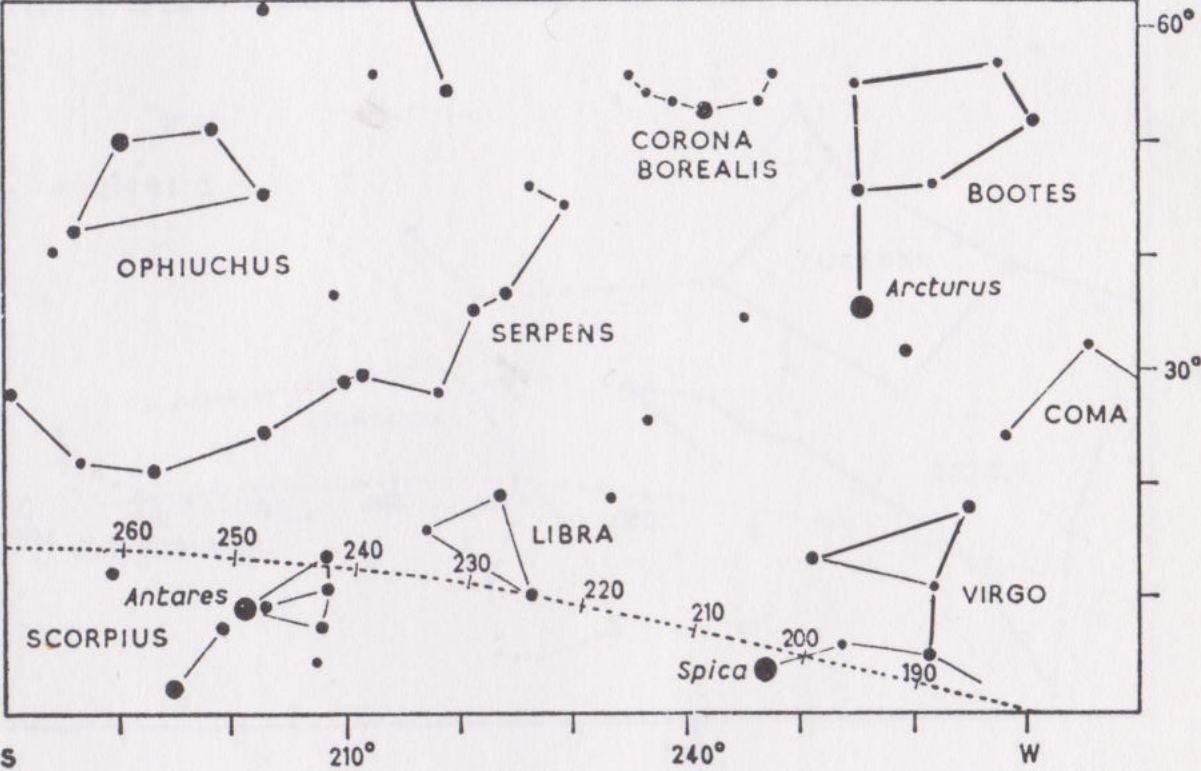
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July 6 at 23 ^h	July 21 at 22 ^h
August 6 at 21 ^h	August 21 at 20 ^h
September 6 at 19 ^h	September 21 at 18 ^h



May 6 at 3^h
June 6 at 1^h
July 6 at 23^h
August 6 at 21^h
September 6 at 19^h

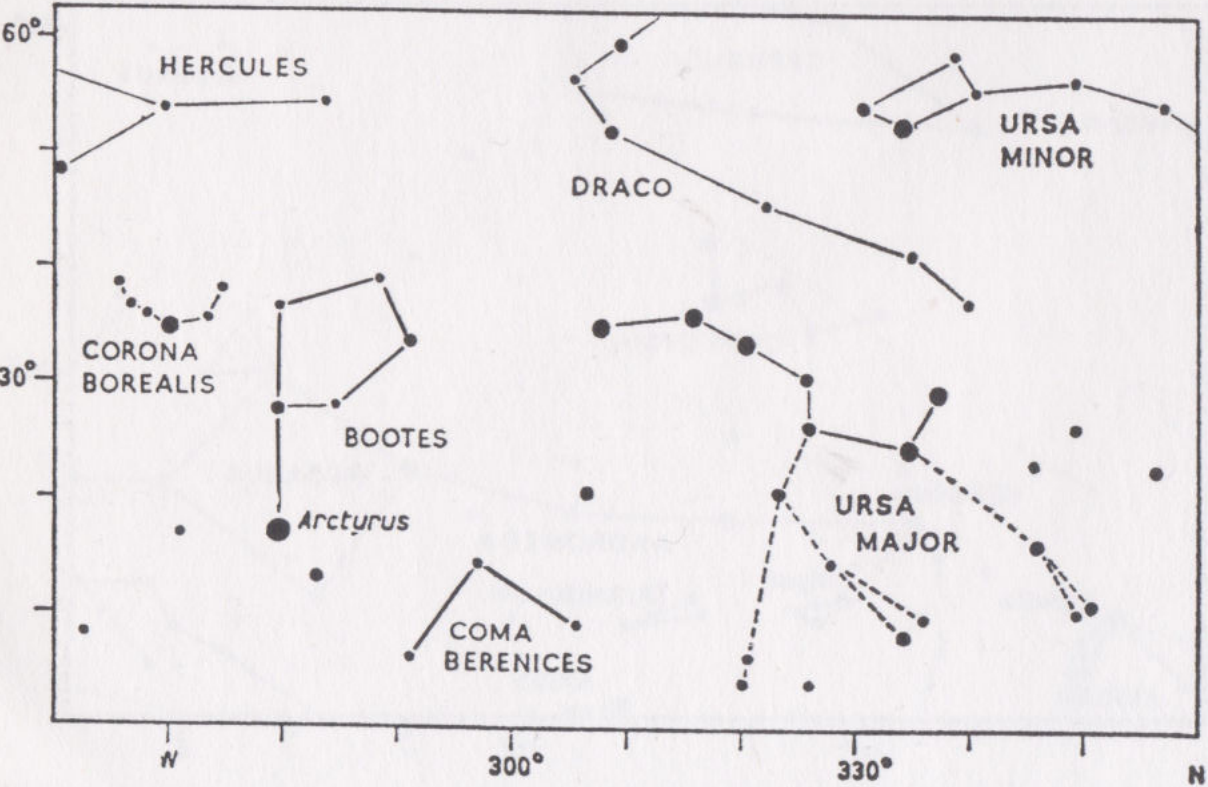
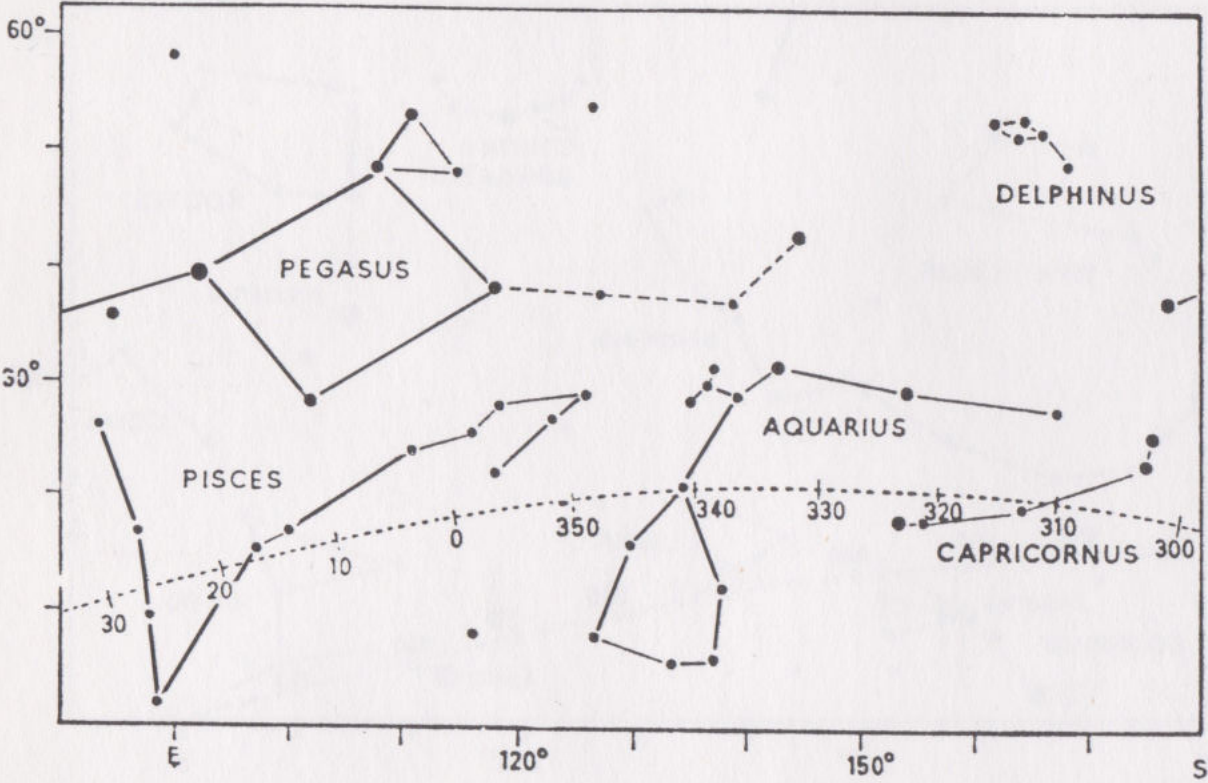
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July 21 at 22^h
August 21 at 20^h
September 21 at 18^h

7R



8L

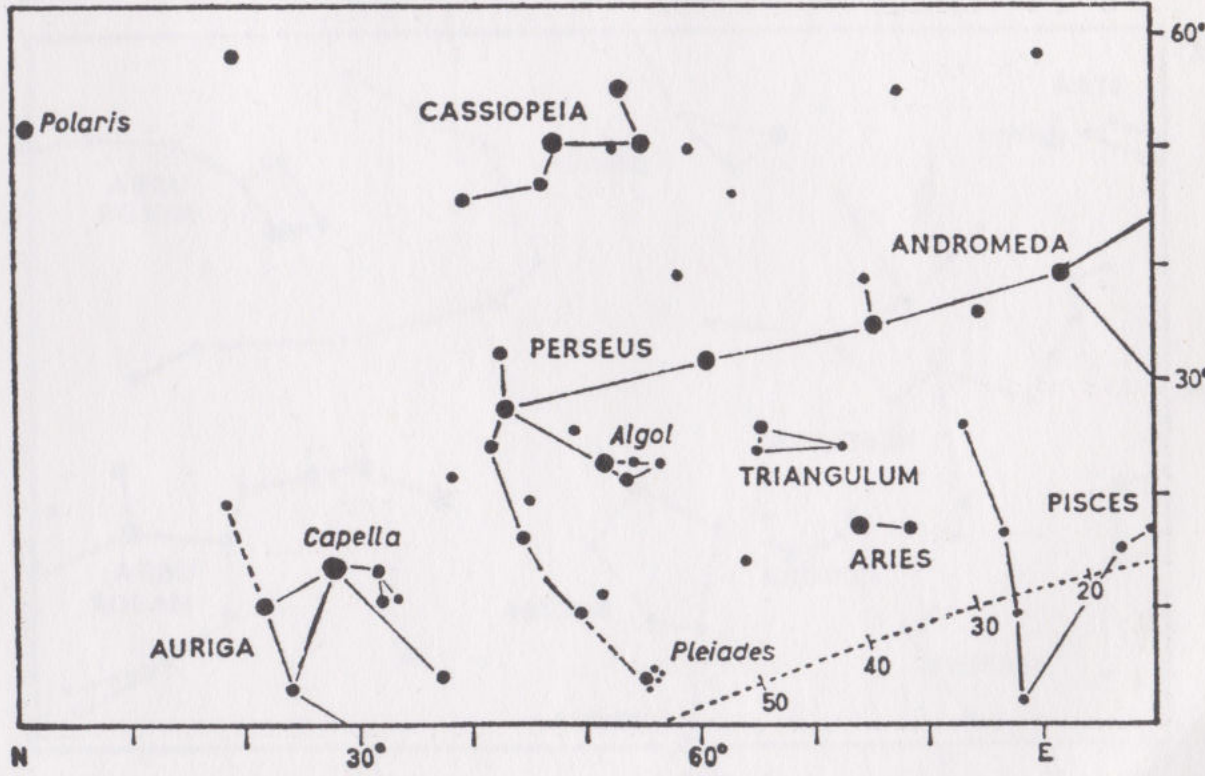
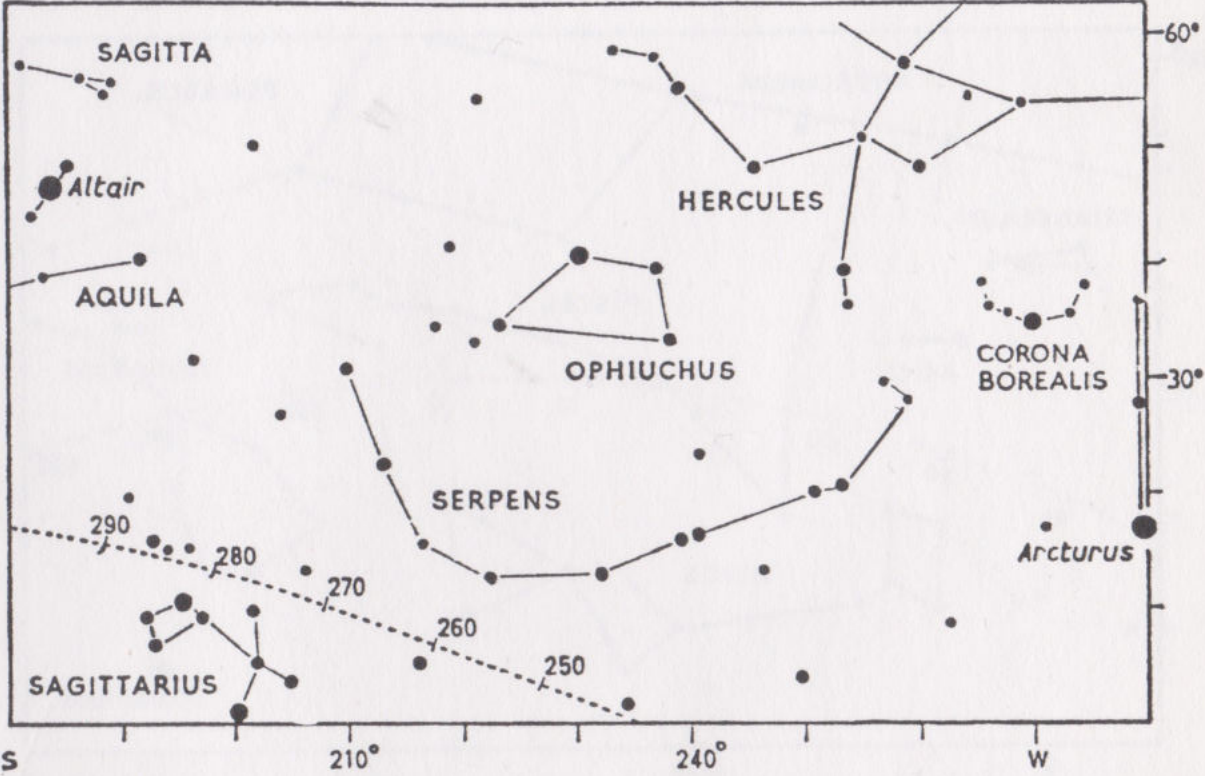
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August 6 at 23 ^h	August 21 at 22 ^h
September 6 at 21 ^h	September 21 at 20 ^h
October 6 at 19 ^h	October 21 at 18 ^h
November 6 at 17 ^h	November 21 at 16 ^h



July 6 at 1^h
August 6 at 23^h
September 6 at 21^h
October 6 at 19^h
November 6 at 17^h

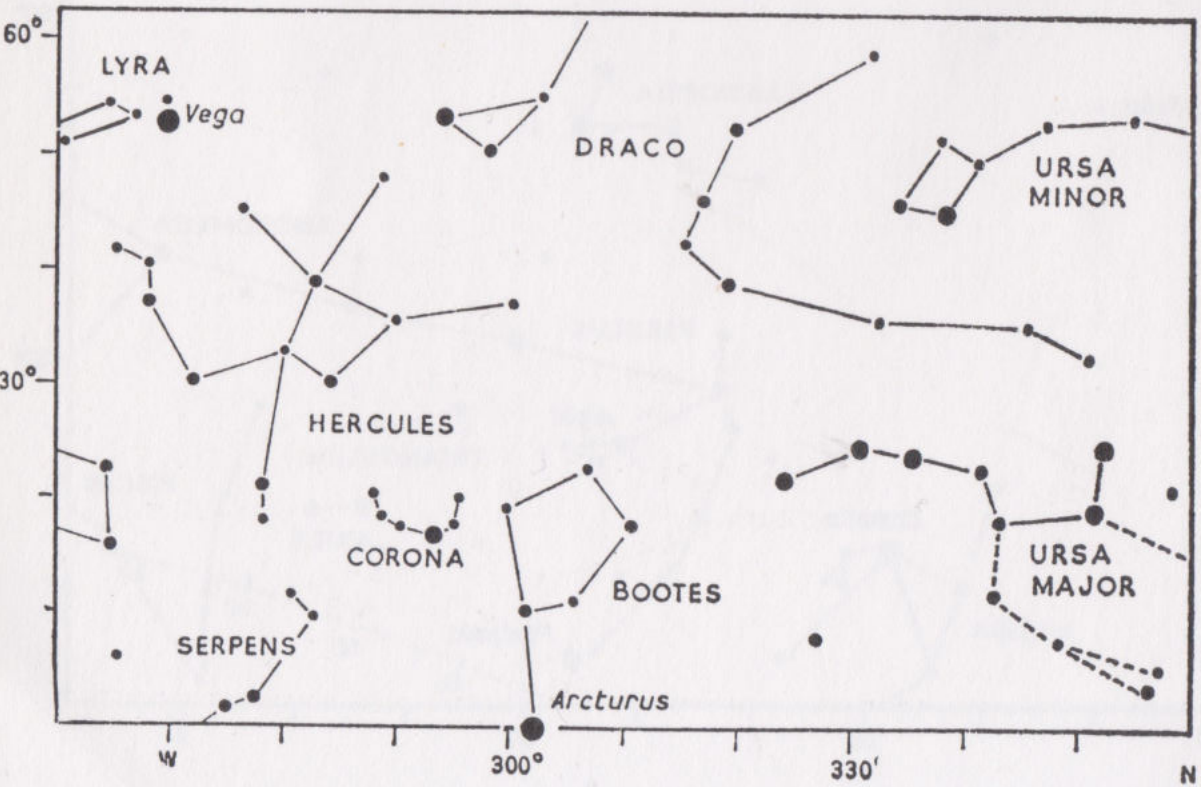
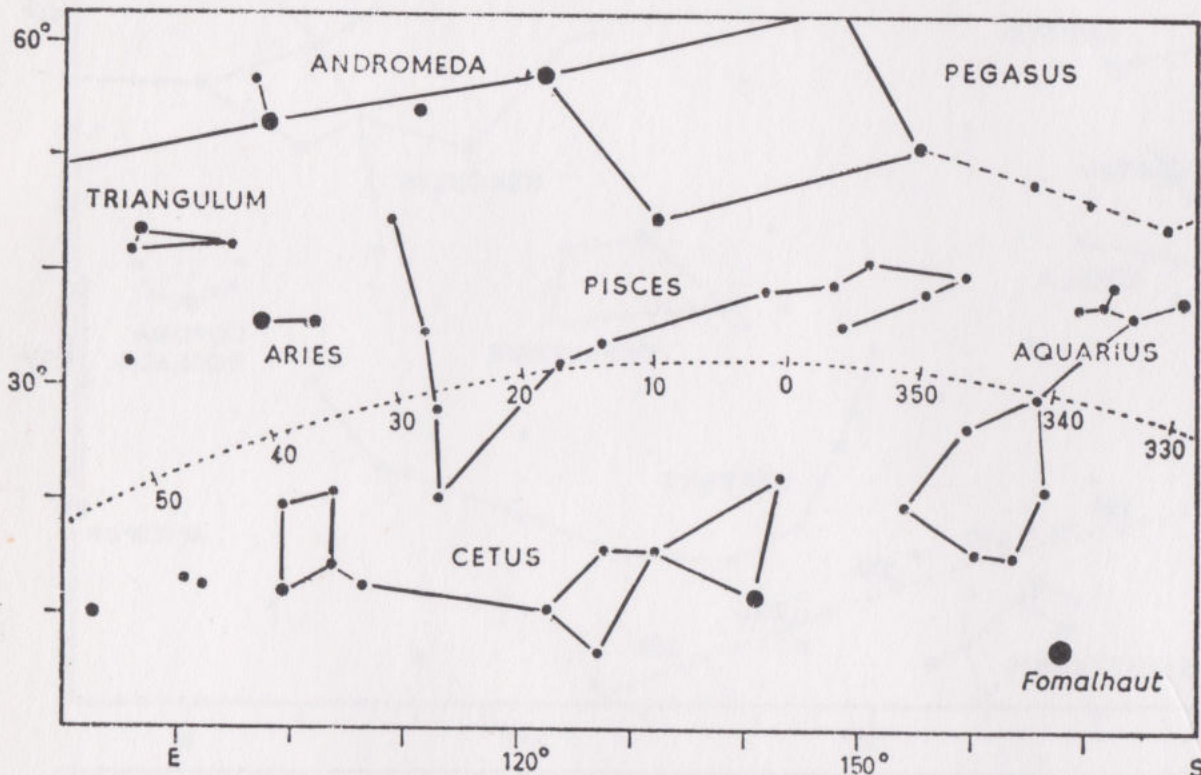
July 21 at midnight
August 21 at 22^h
September 21 at 20^h
October 21 at 18^h
November 21 at 16^h

8R



9L

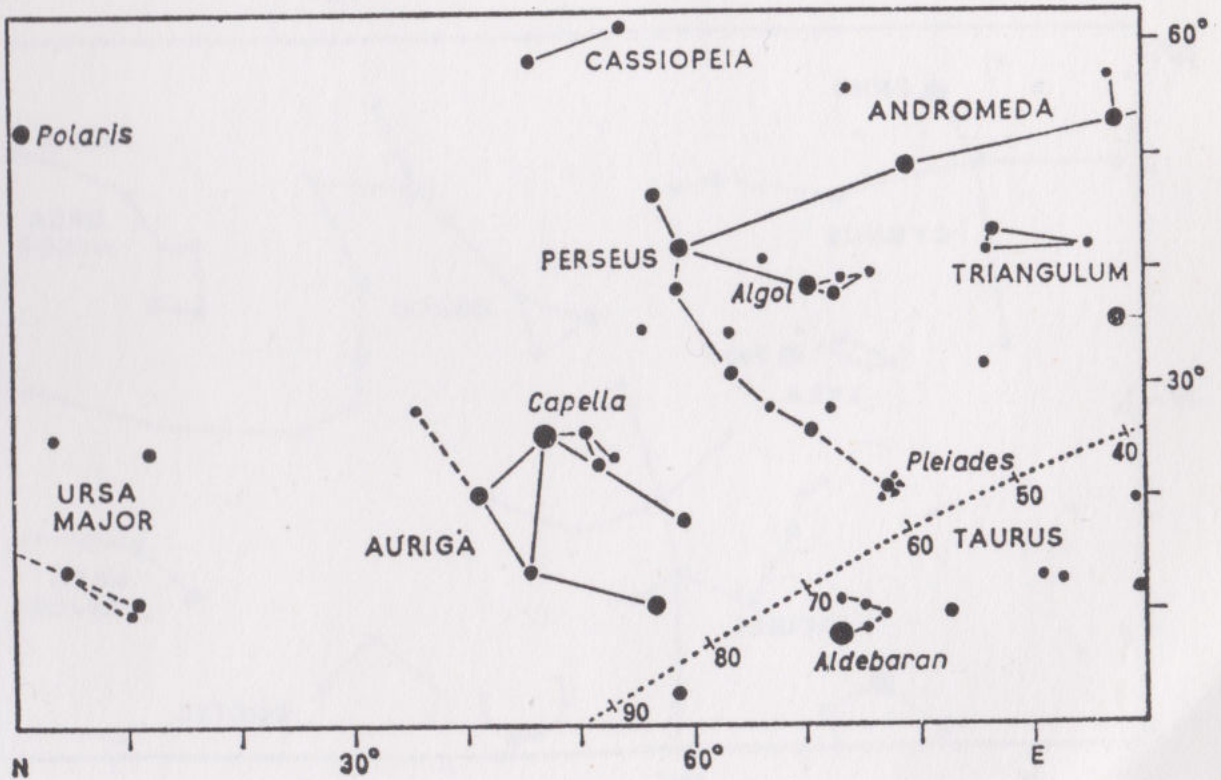
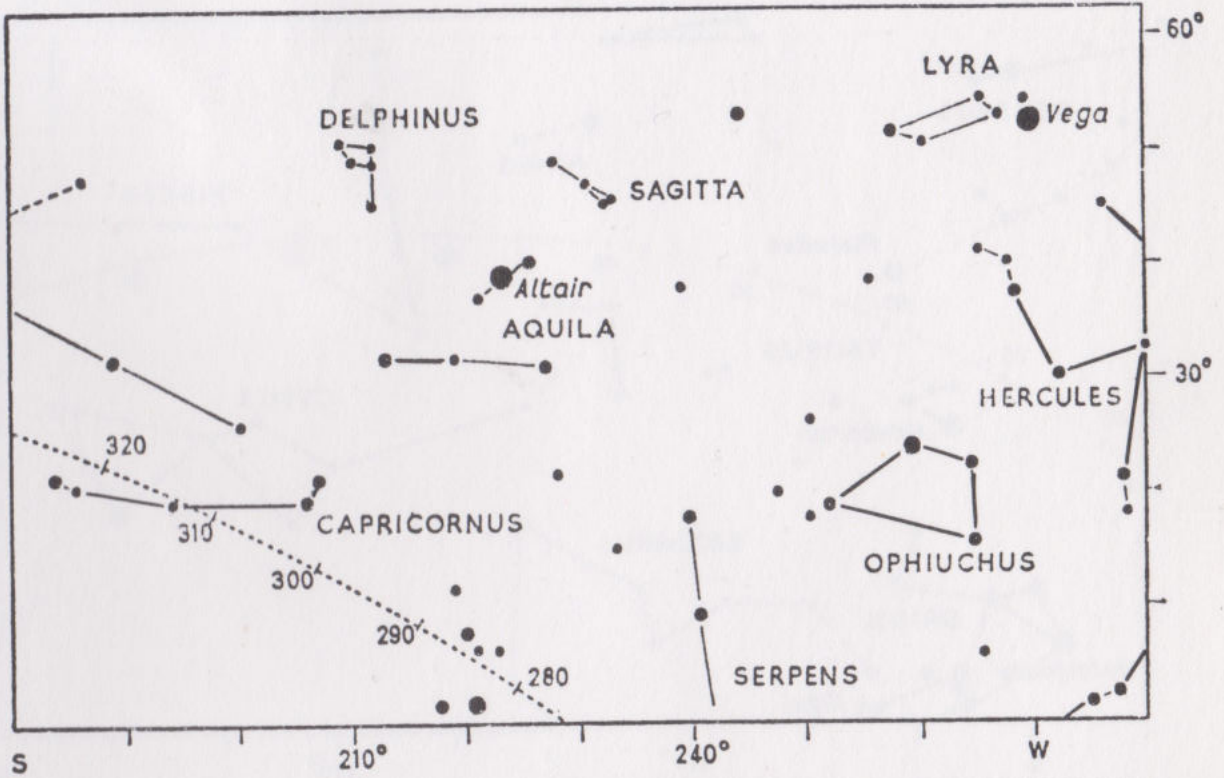
August 6 at 1 ^h	August 21 at midnight
September 6 at 23 ^h	September 21 at 22 ^h
October 6 at 21 ^h	October 21 at 20 ^h
November 6 at 19 ^h	November 21 at 18 ^h
December 6 at 17 ^h	December 21 at 16 ^h



August 6 at 1^h
 September 6 at 23^h
 October 6 at 21^h
 November 6 at 19^h
 December 6 at 17^h

August 21 at midnight
 September 21 at 22^h
 October 21 at 20^h
 November 21 at 18^h
 December 21 at 16^h

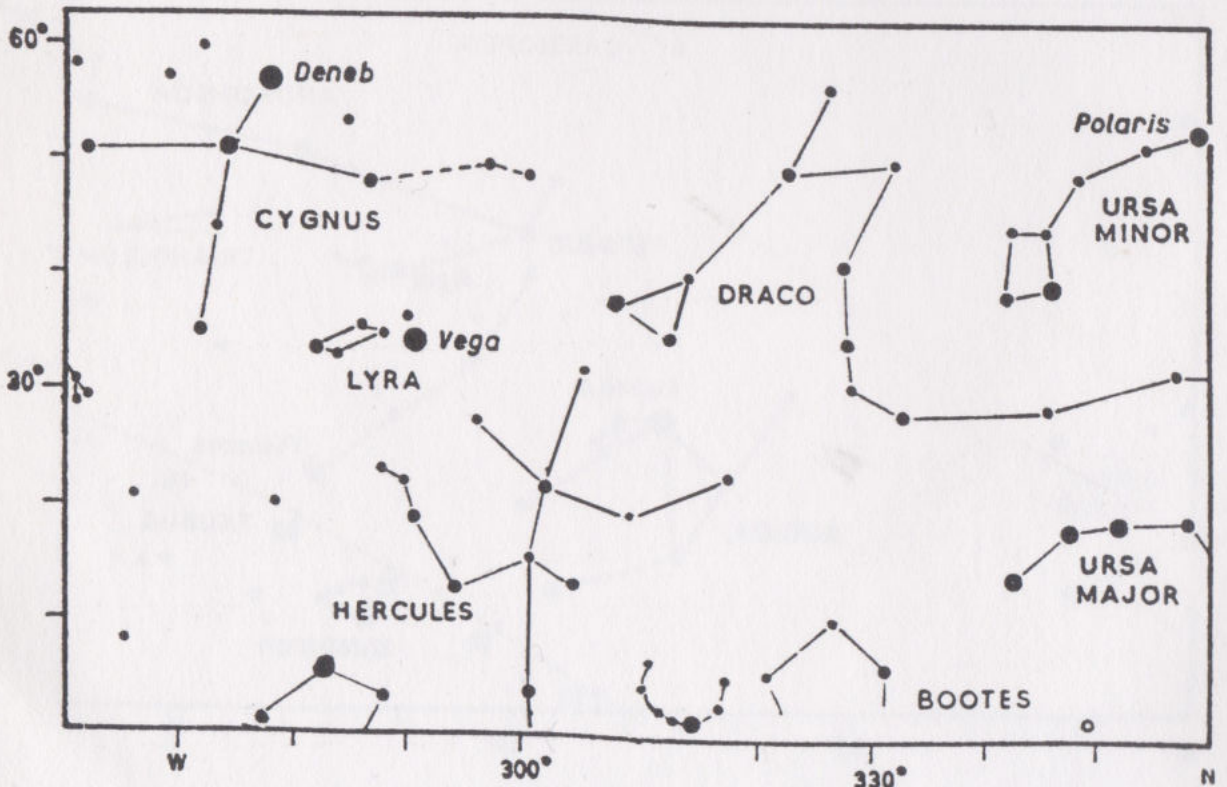
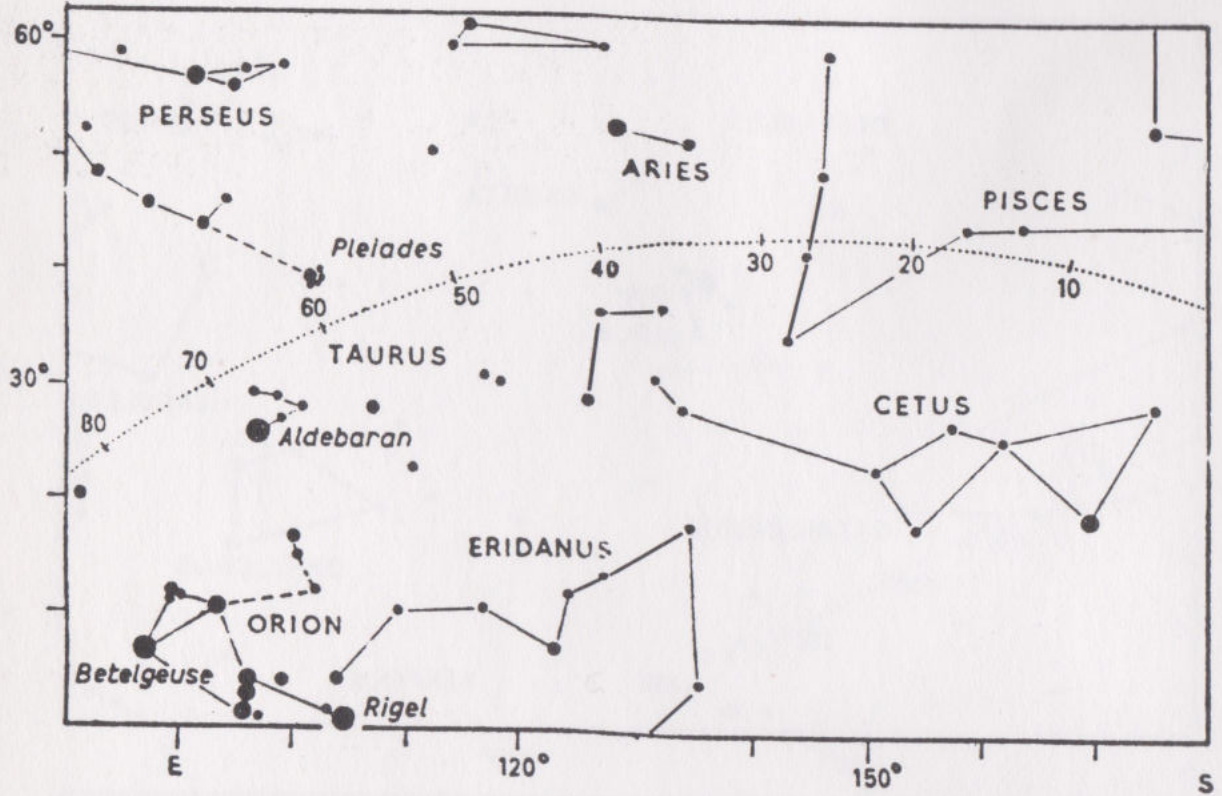
9R



10L

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September 6 at 1^h
October 6 at 23^h
November 6 at 21^h
December 6 at 19^h

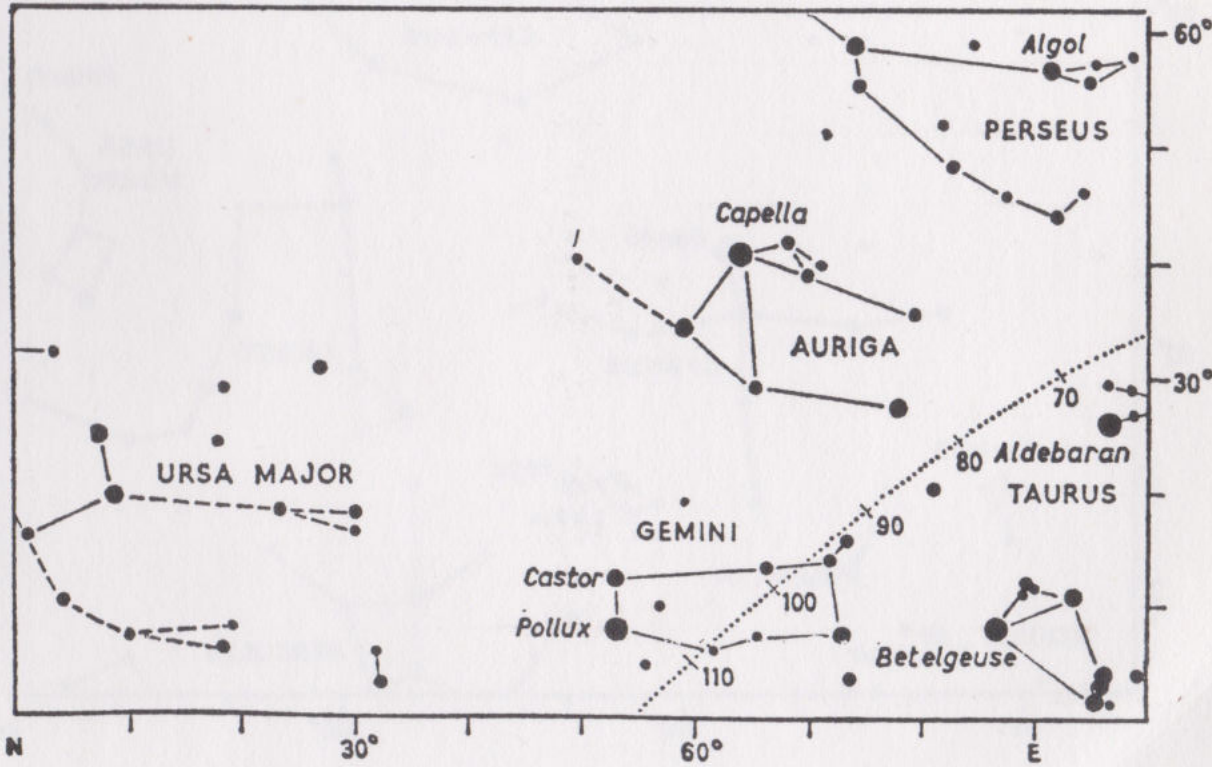
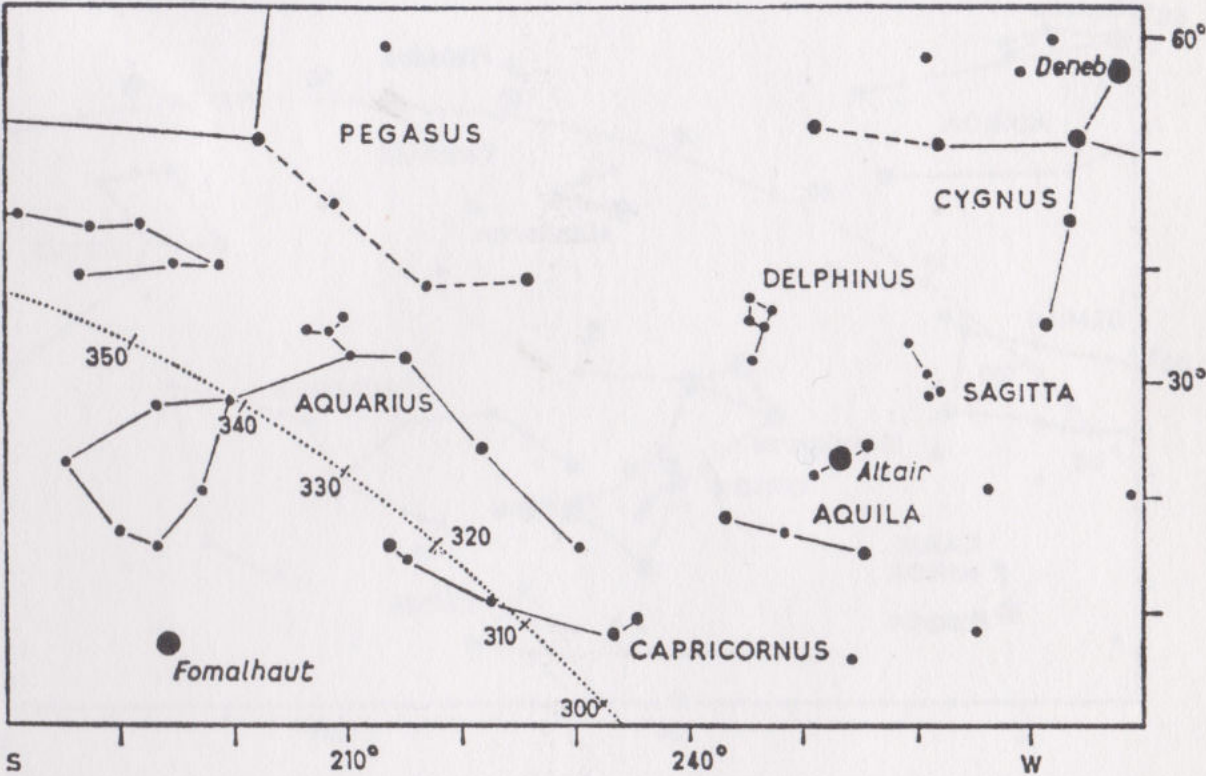
August 21 at 2^h
September 21 at midnight
October 21 at 22^h
November 21 at 20^h
December 21 at 18^h



August 6 at 3^h
September 6 at 1^h
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November 6 at 21^h
December 6 at 19^h

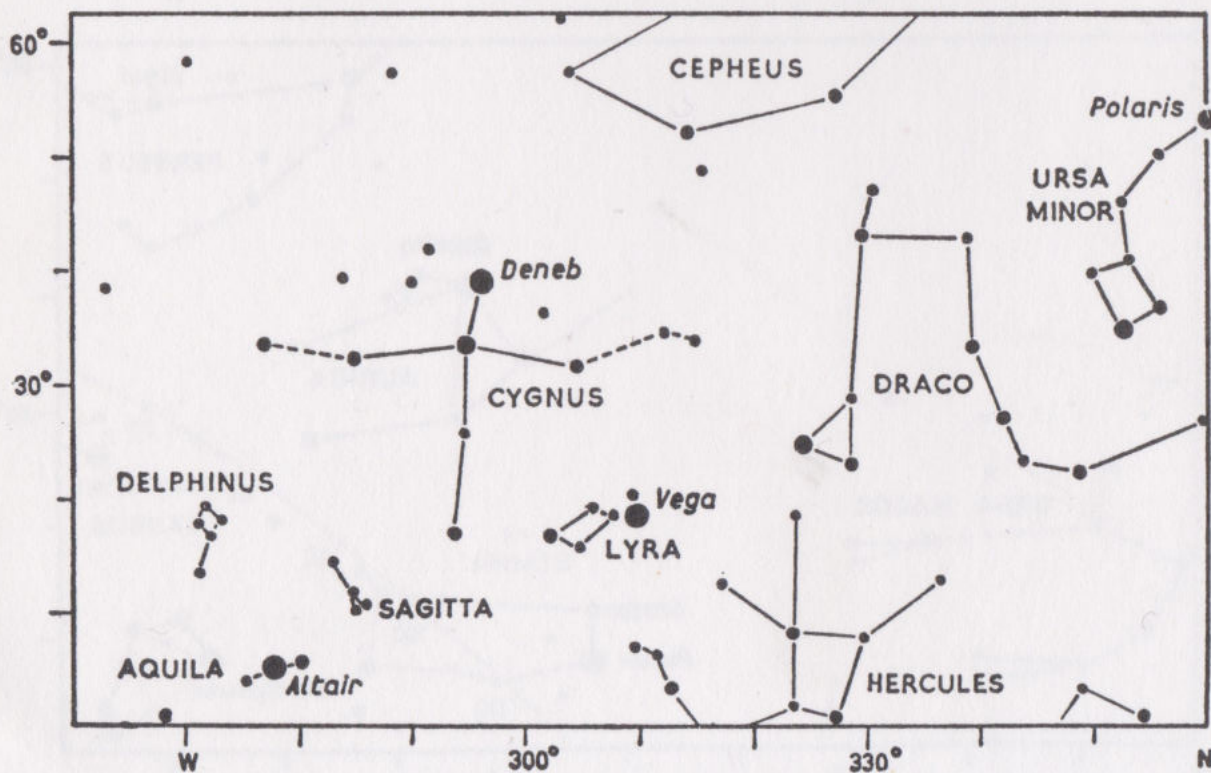
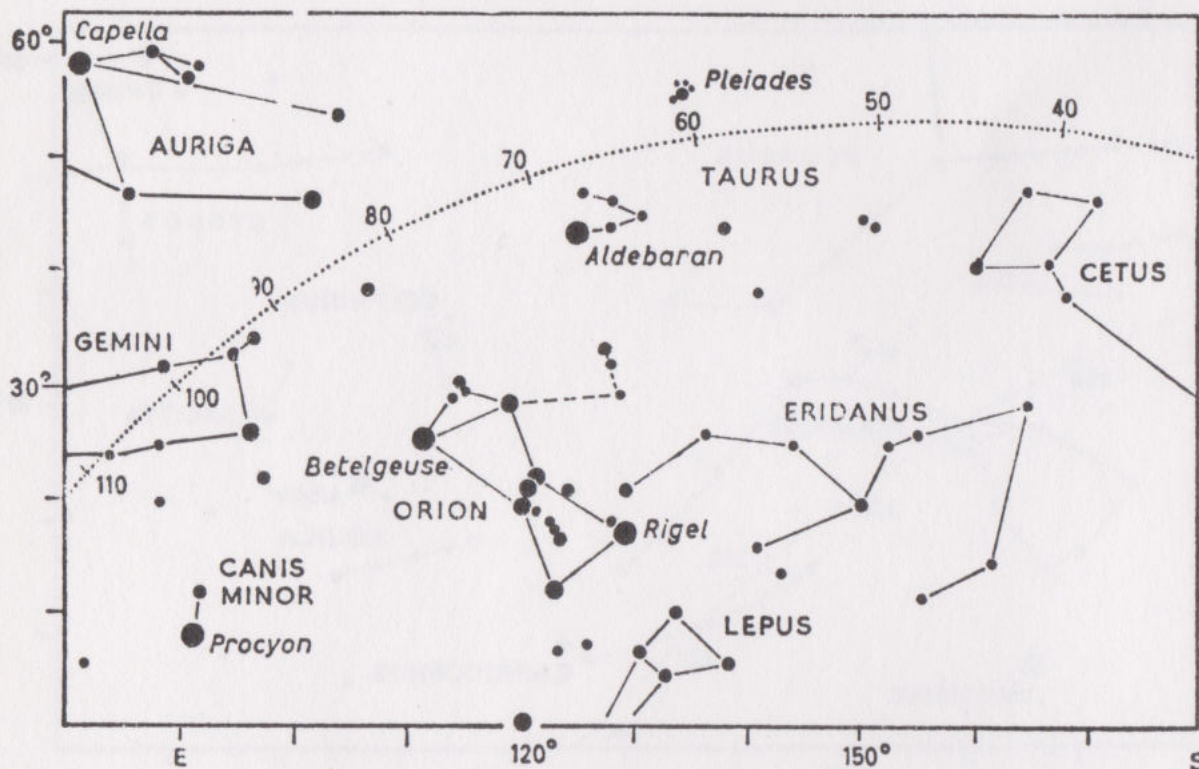
August 21 at 2^h
September 21 at midnight
October 21 at 22^h
November 21 at 20^h
December 21 at 18^h

10R



11L

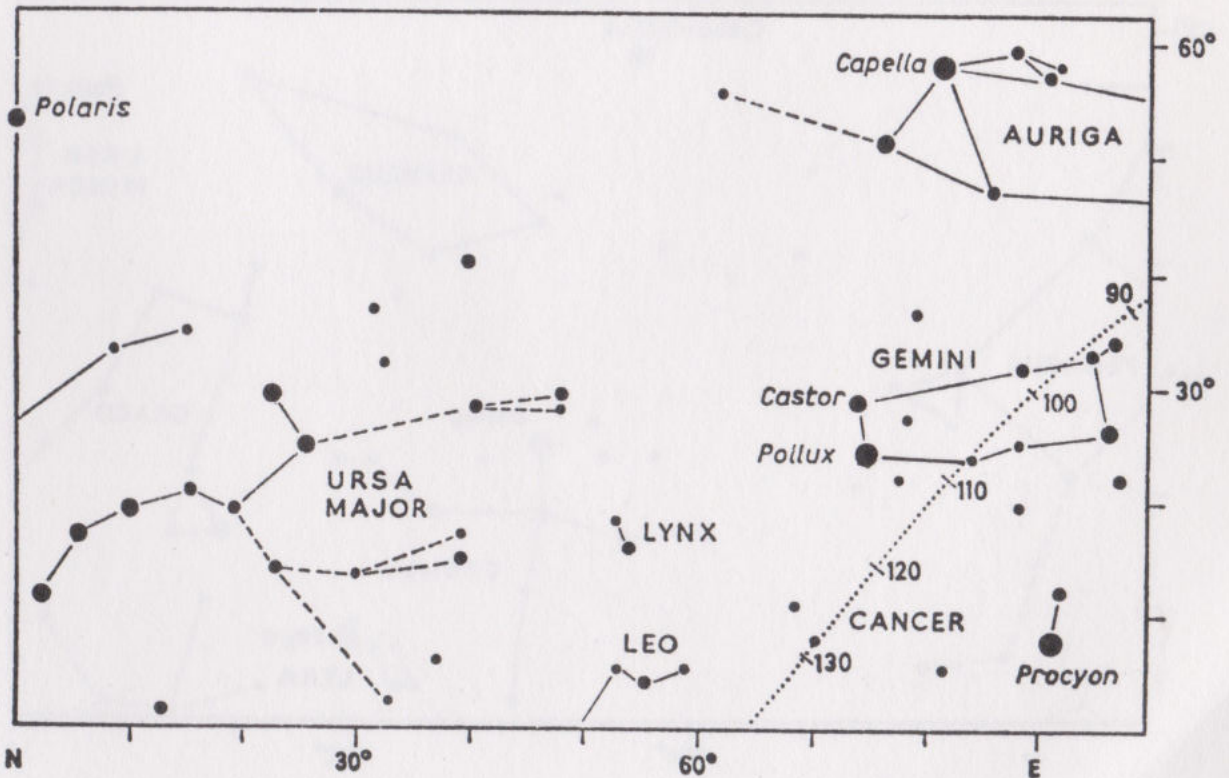
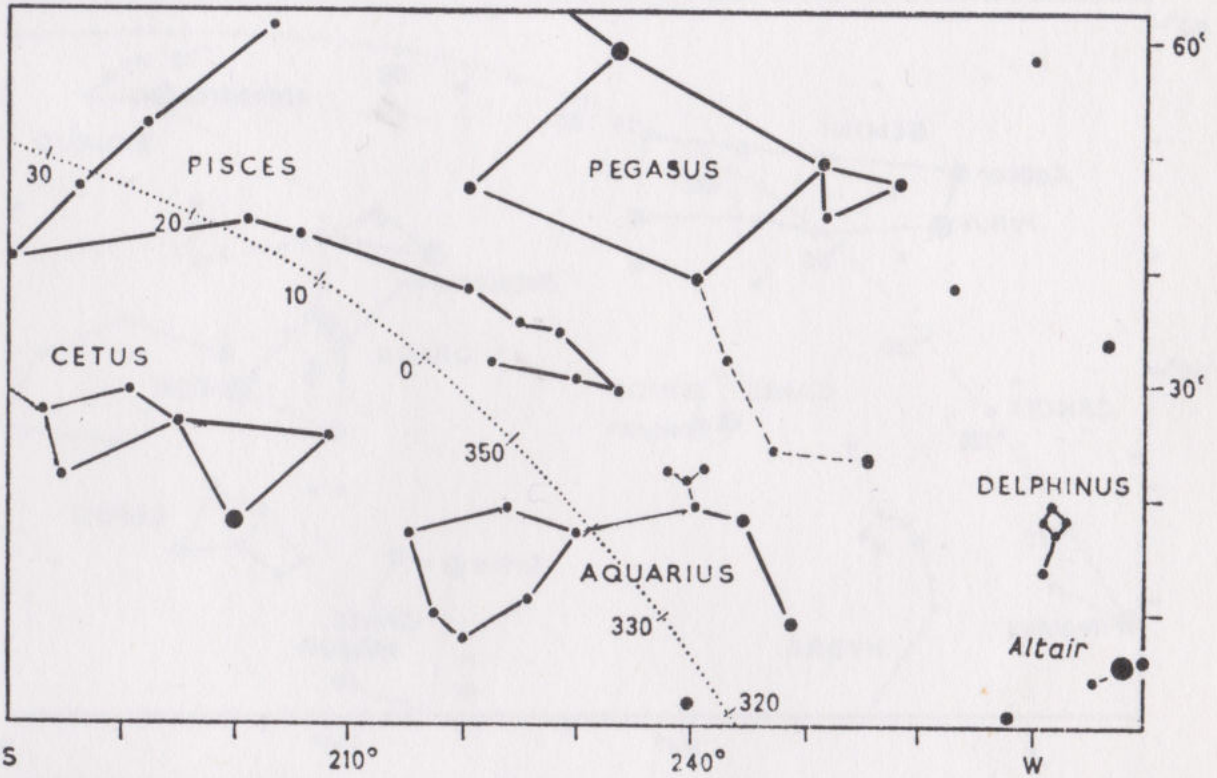
September 6 at 3 ^h	September 21 at 2 ^h
October 6 at 1 ^h	October 21 at midnight
November 6 at 23 ^h	November 21 at 22 ^h
December 6 at 21 ^h	December 21 at 20 ^h
January 6 at 19 ^h	January 21 at 18 ^h



September 6 at 3^h
 October 6 at 1^h
 November 6 at 23^h
 December 6 at 21^h
 January 6 at 19^h

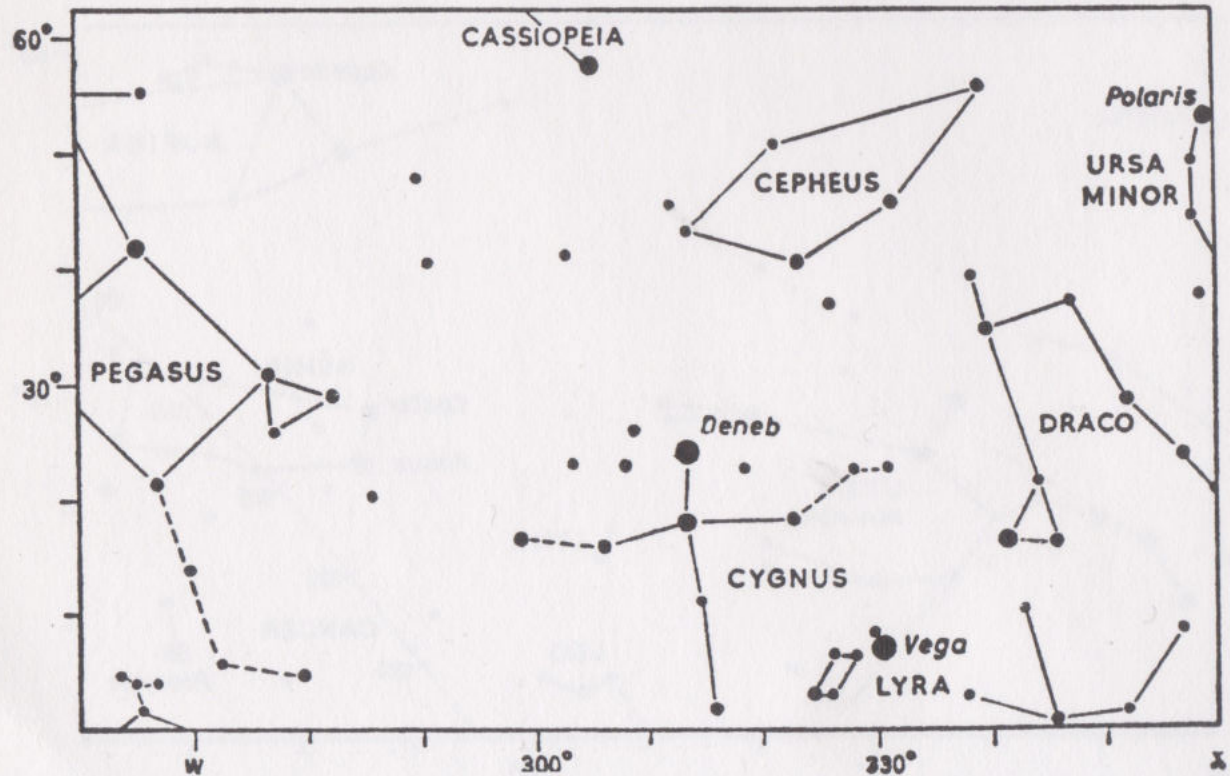
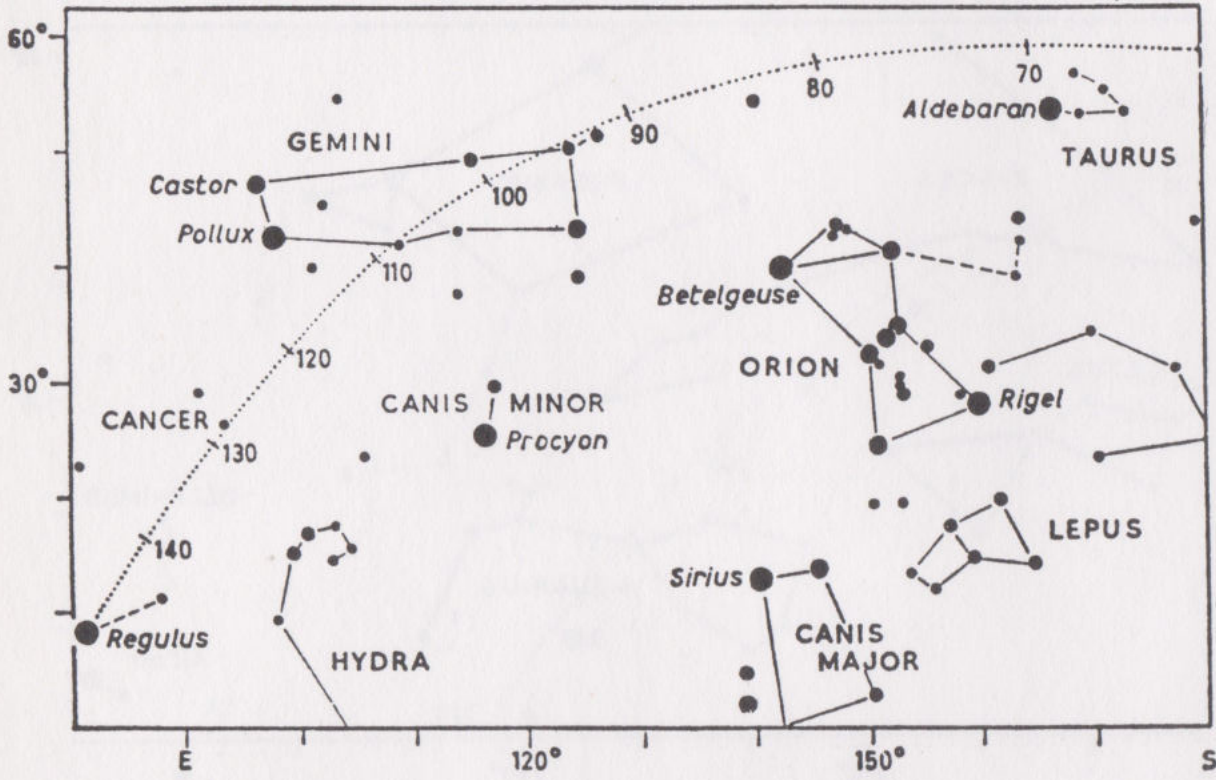
September 21 at 2^h
 October 21 at midnight
 November 21 at 22^h
 December 21 at 20^h
 January 21 at 18^h

11R



12L

October 6 at 3 ^h	October 21 at 2 ^h
November 6 at 1 ^h	November 21 at midnight
December 6 at 23 ^h	December 21 at 22 ^h
January 6 at 21 ^h	January 21 at 20 ^h
February 6 at 19 ^h	February 21 at 18 ^h

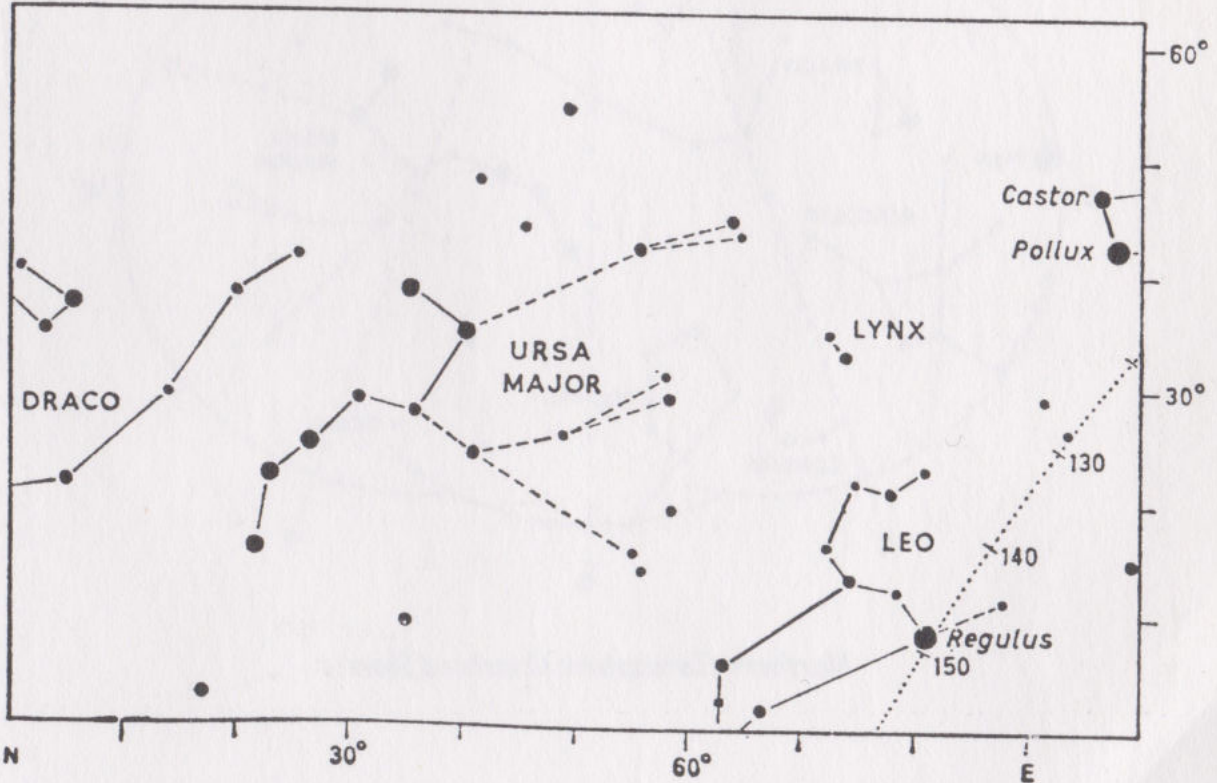
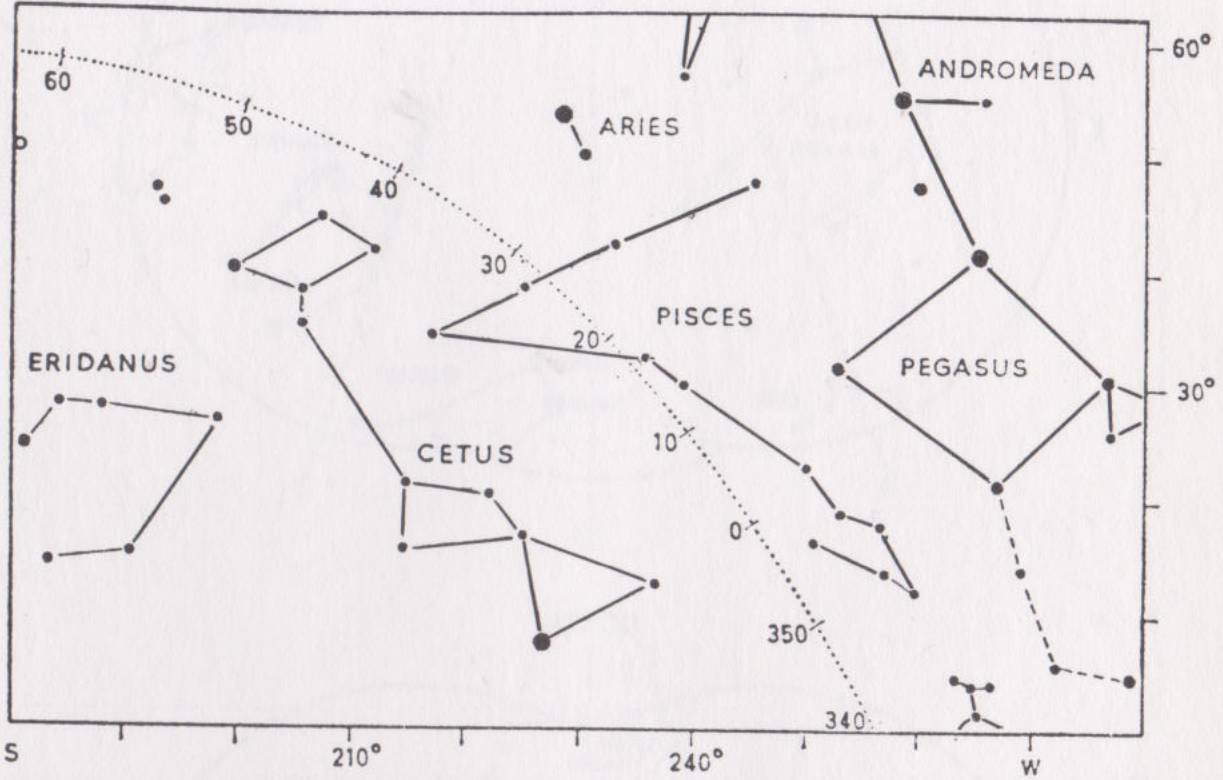


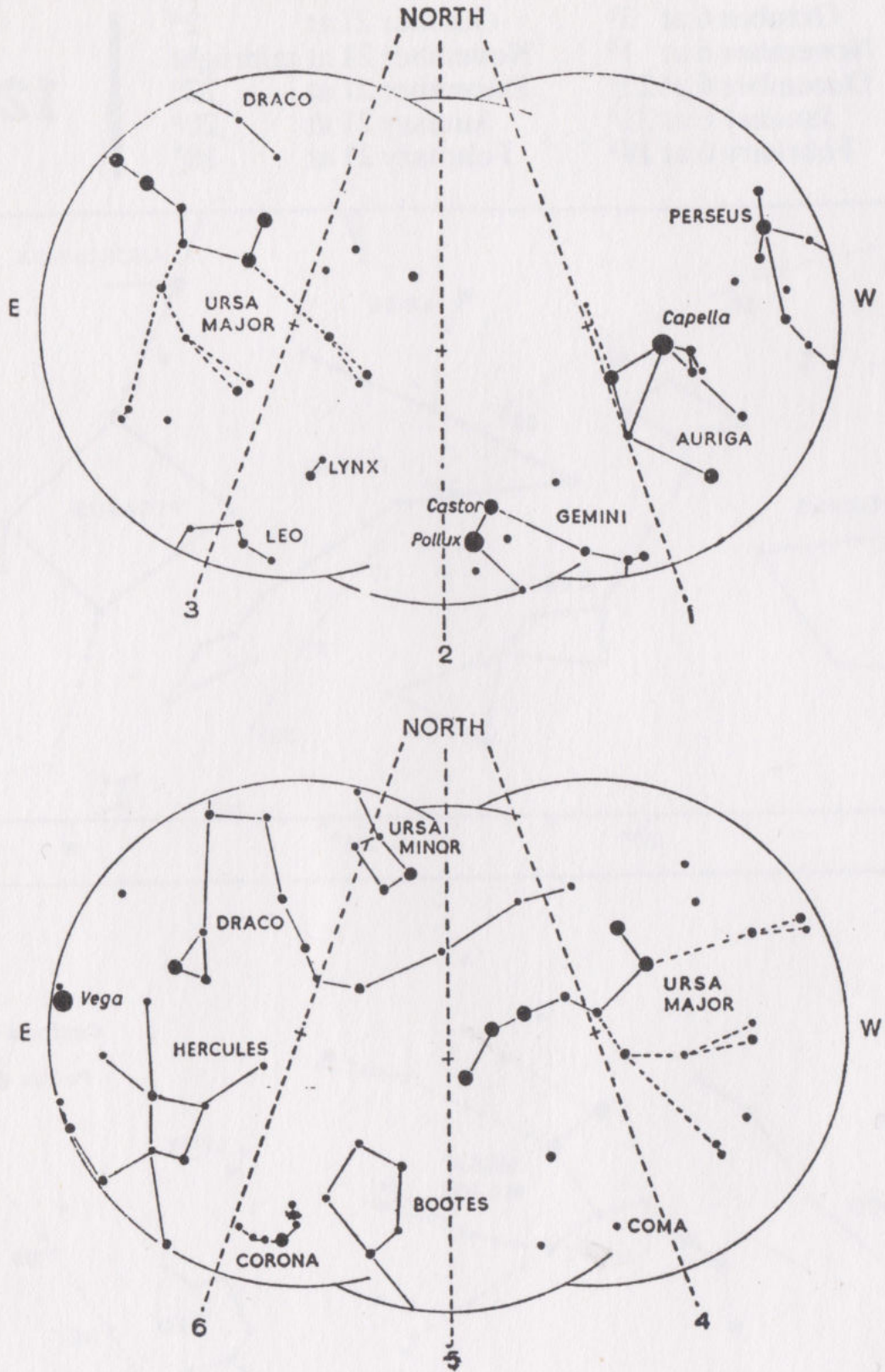
NORTHERN STAR CHARTS

October 6 at 3^h
 November 6 at 1^h
 December 6 at 23^h
 January 6 at 21^h
 February 6 at 19^h

October 21 at 2^h
 November 21 at midnight
 December 21 at 22^h
 January 21 at 20^h
 February 21 at 18^h

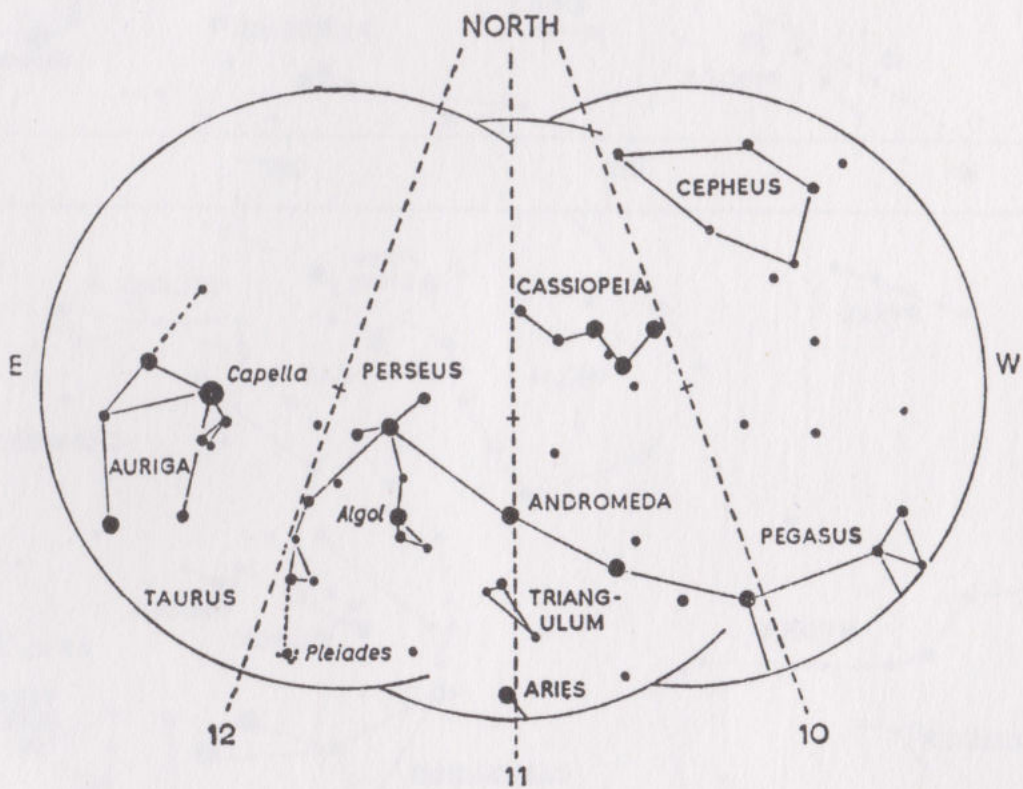
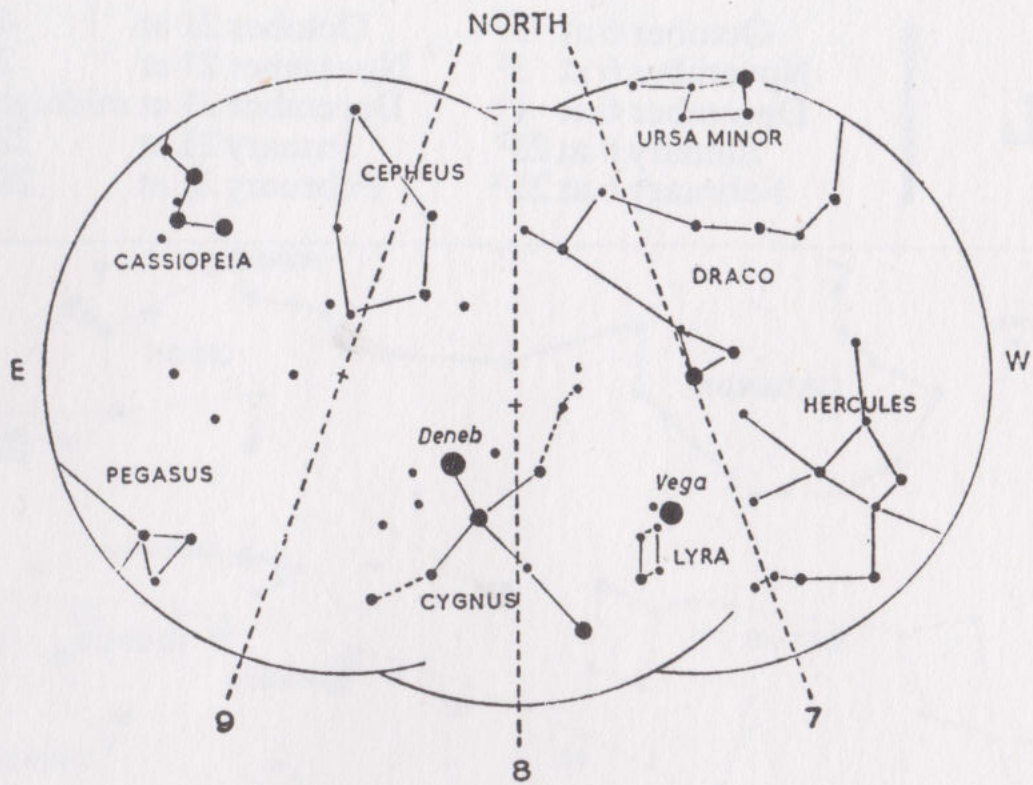
12R





Northern Hemisphere Overhead Stars

NORTHERN STAR CHARTS

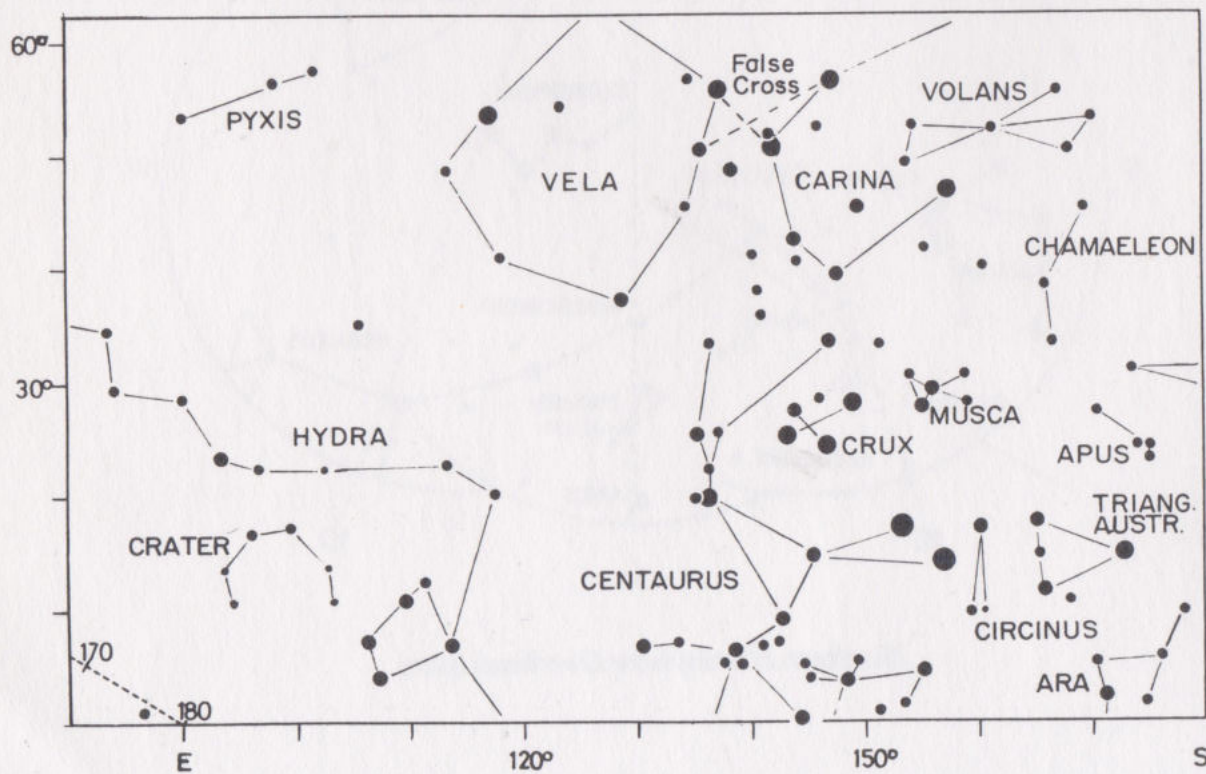
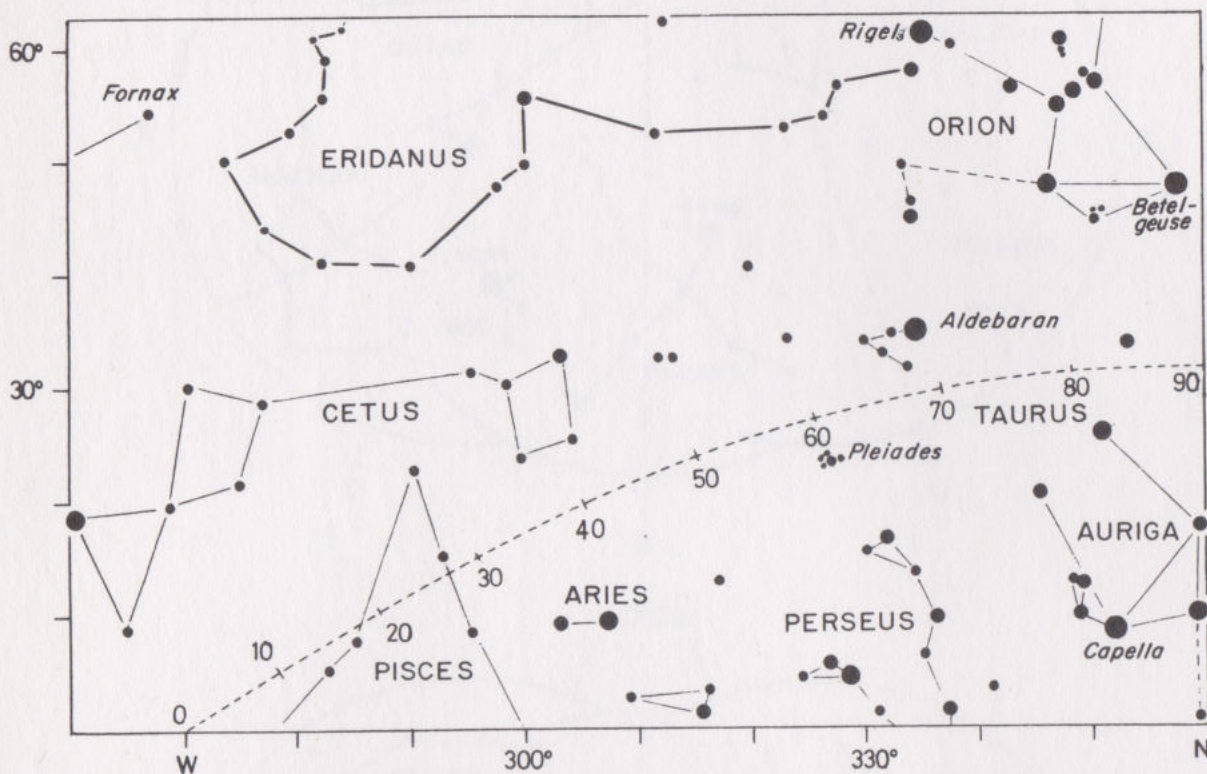


Northern Hemisphere Overhead Stars

1L

October 6 at 5^h
November 6 at 3^h
December 6 at 1^h
January 6 at 23^h
February 6 at 21^h

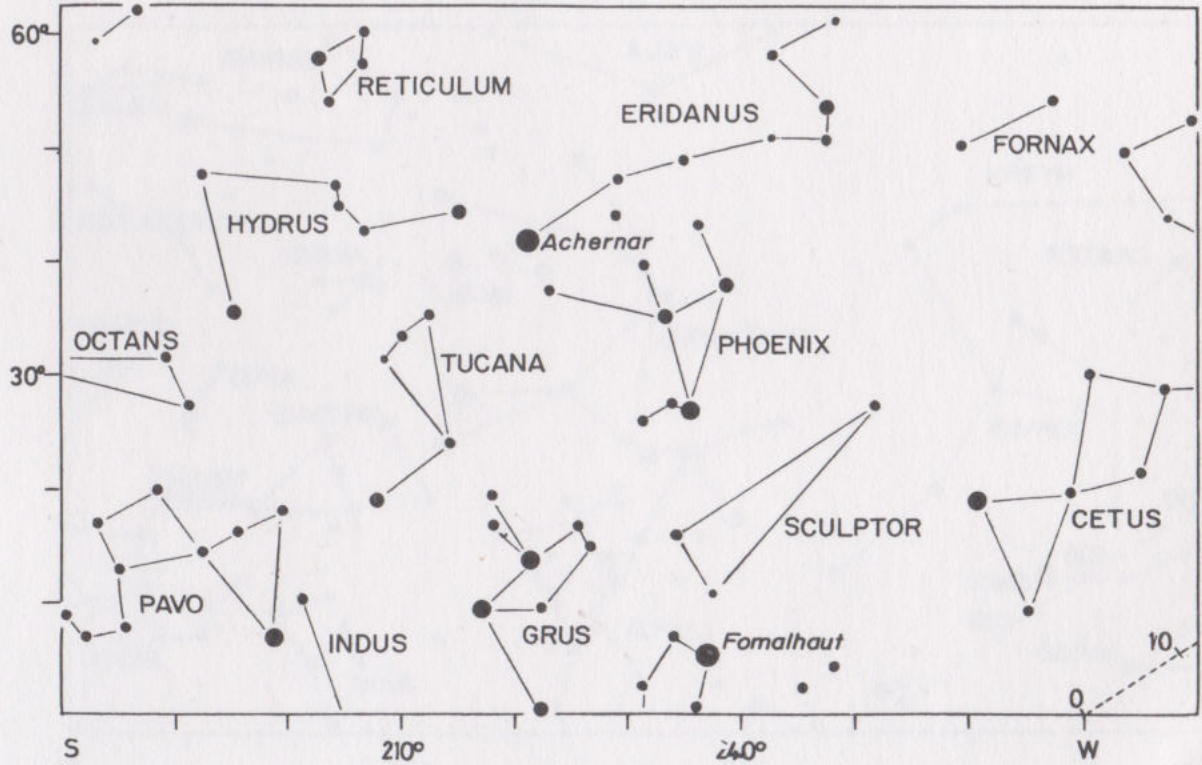
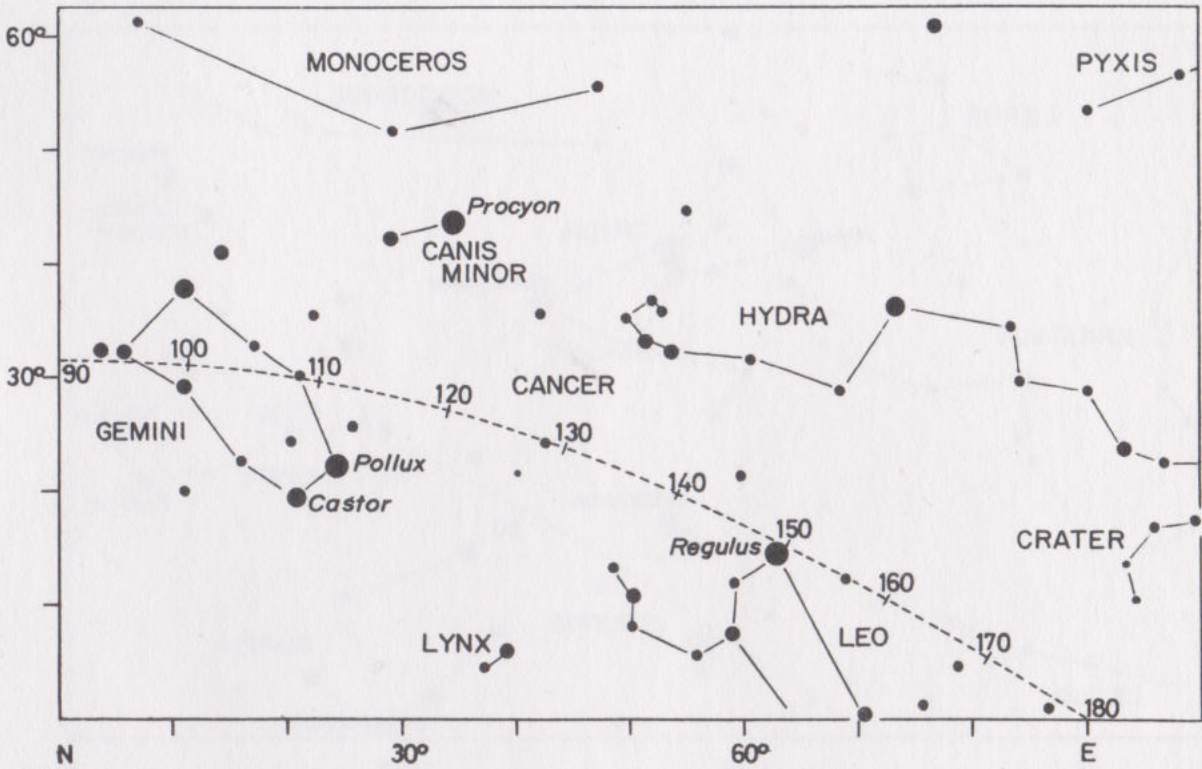
October 21 at 4^h
November 21 at 2^h
December 21 at midnight
January 21 at 22^h
February 21 at 20^h



October 6 at 5^h
November 6 at 3^h
December 6 at 1^h
January 6 at 23^h
February 6 at 21^h

October 21 at 4ⁿ
November 21 at 2^h
December 21 at midnight
January 21 at 22^h
February 21 at 20^h

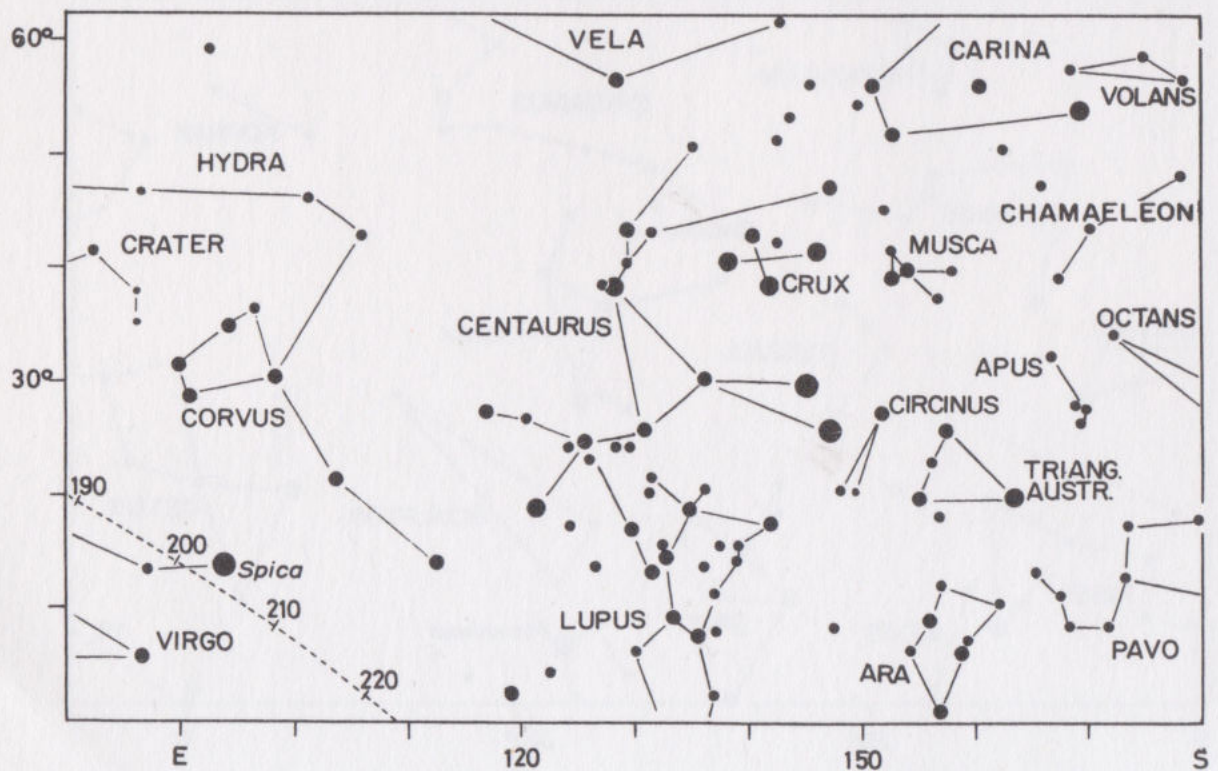
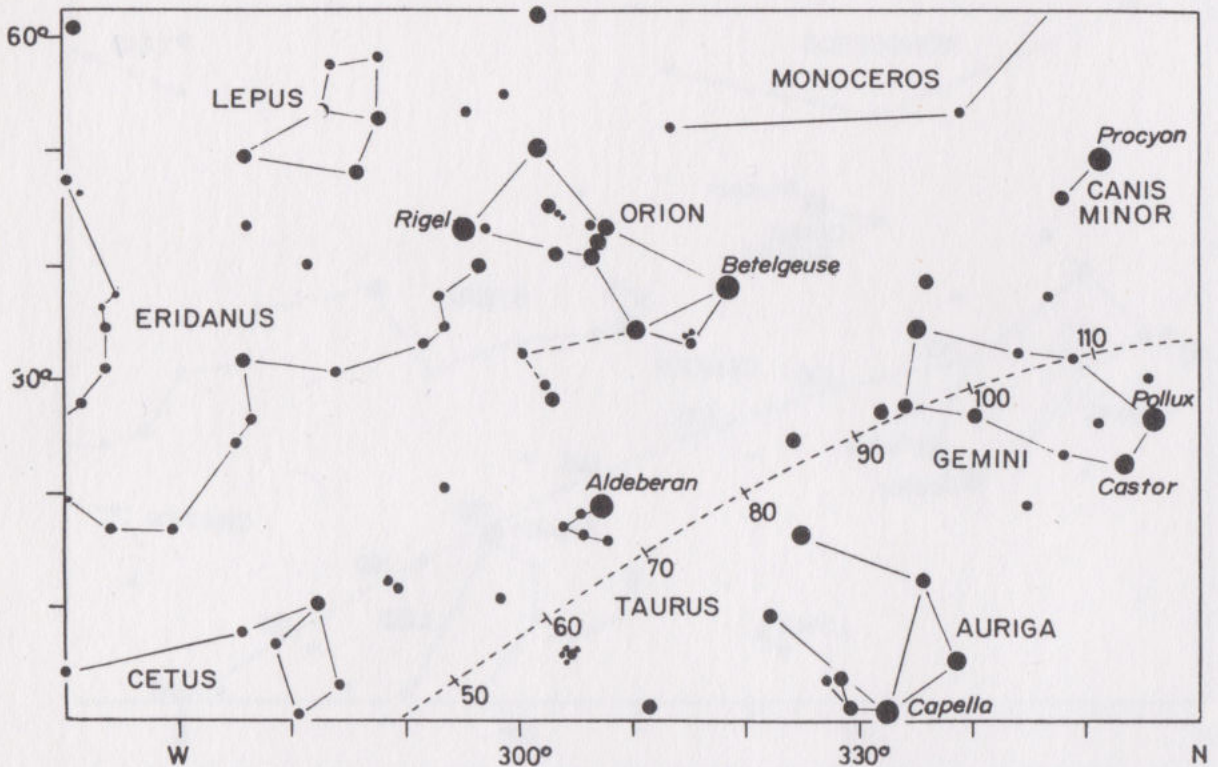
1R



2L

November 6 at 5^h
December 6 at 3^h
January 6 at 1^h
February 6 at 23^h
March 6 at 21^h

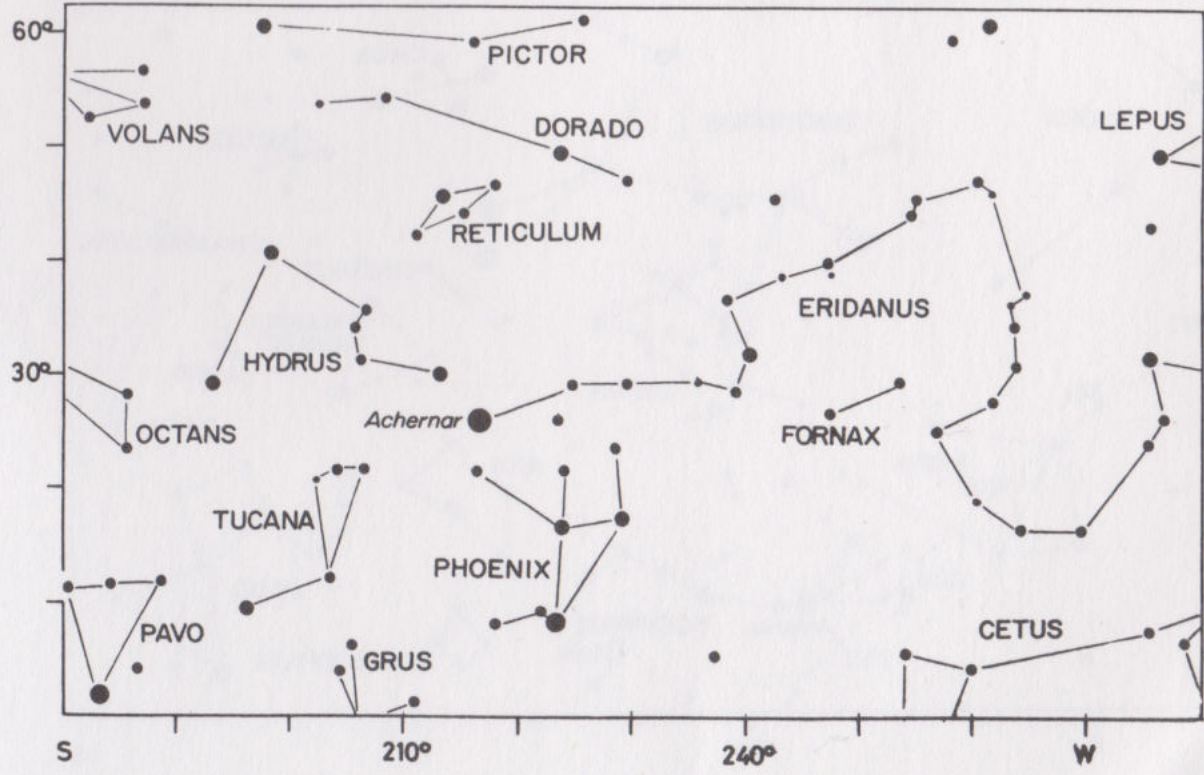
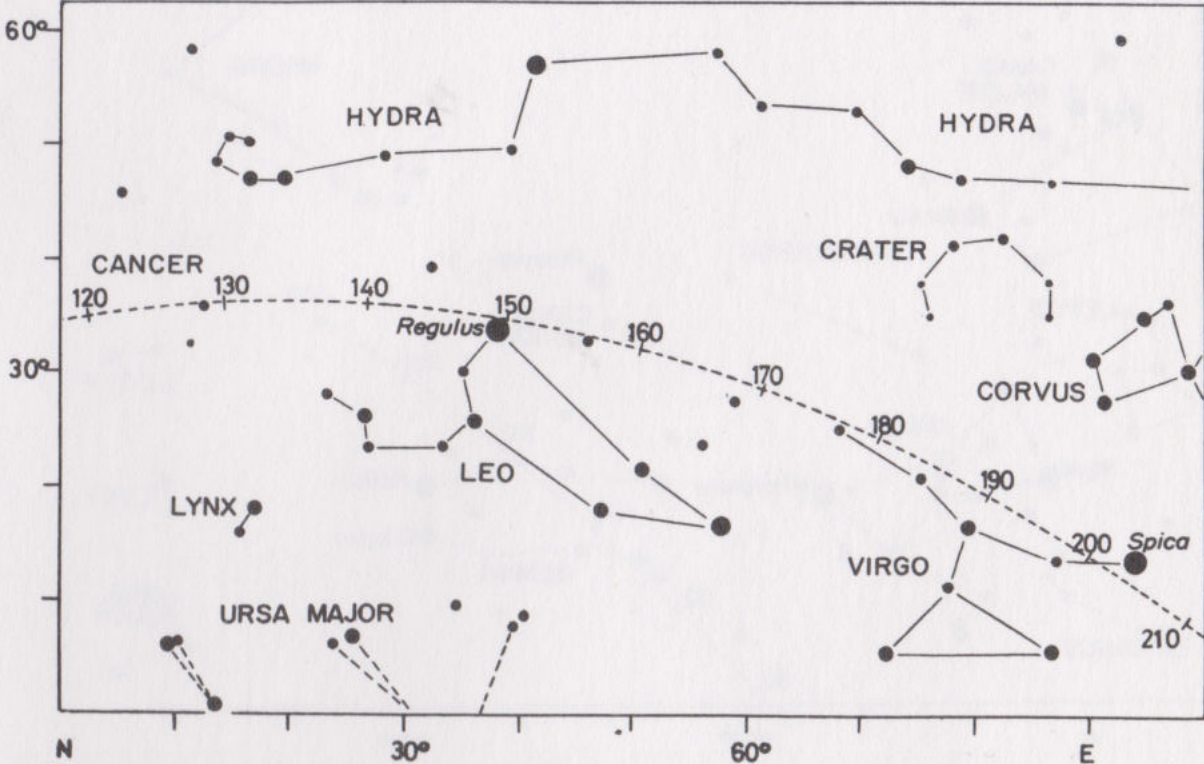
November 21 at 4^h
December 21 at 2^h
January 21 at midnight
February 21 at 22^h
March 21 at 20^h



November 6 at 5^h
December 6 at 3^h
January 6 at 1^h
February 6 at 23^h
March 6 at 21^h

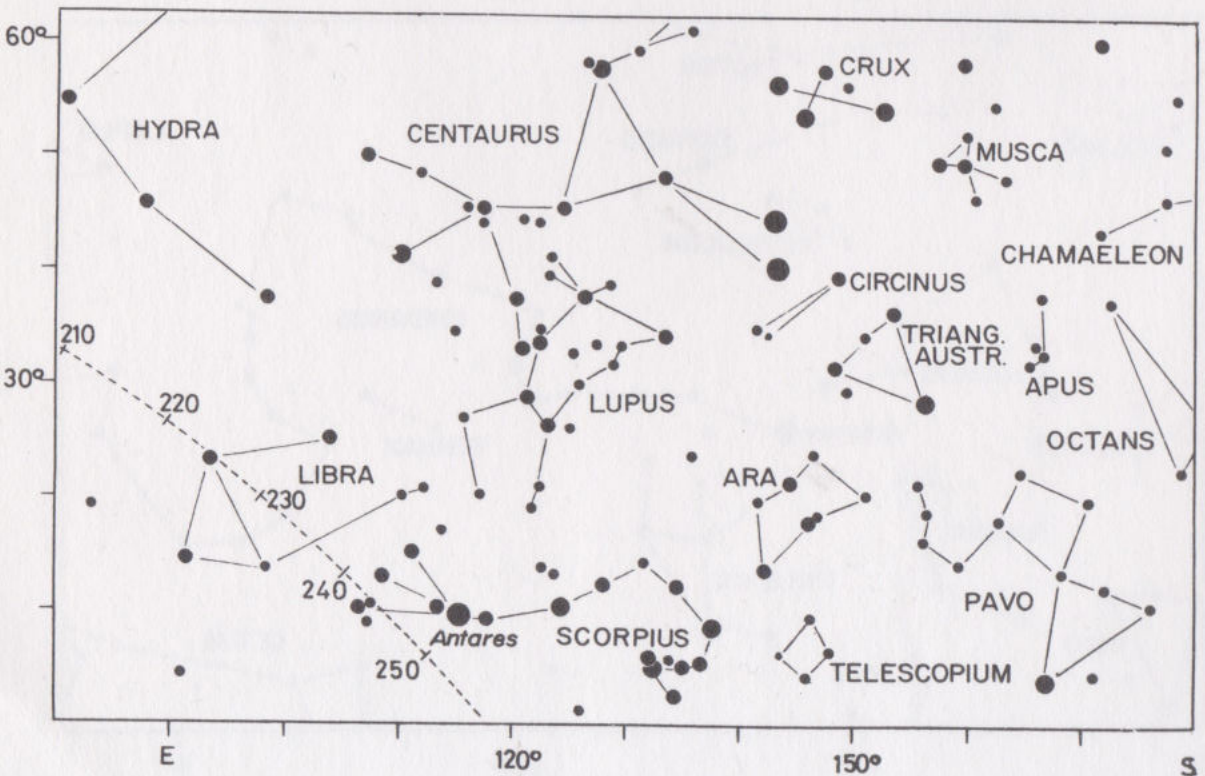
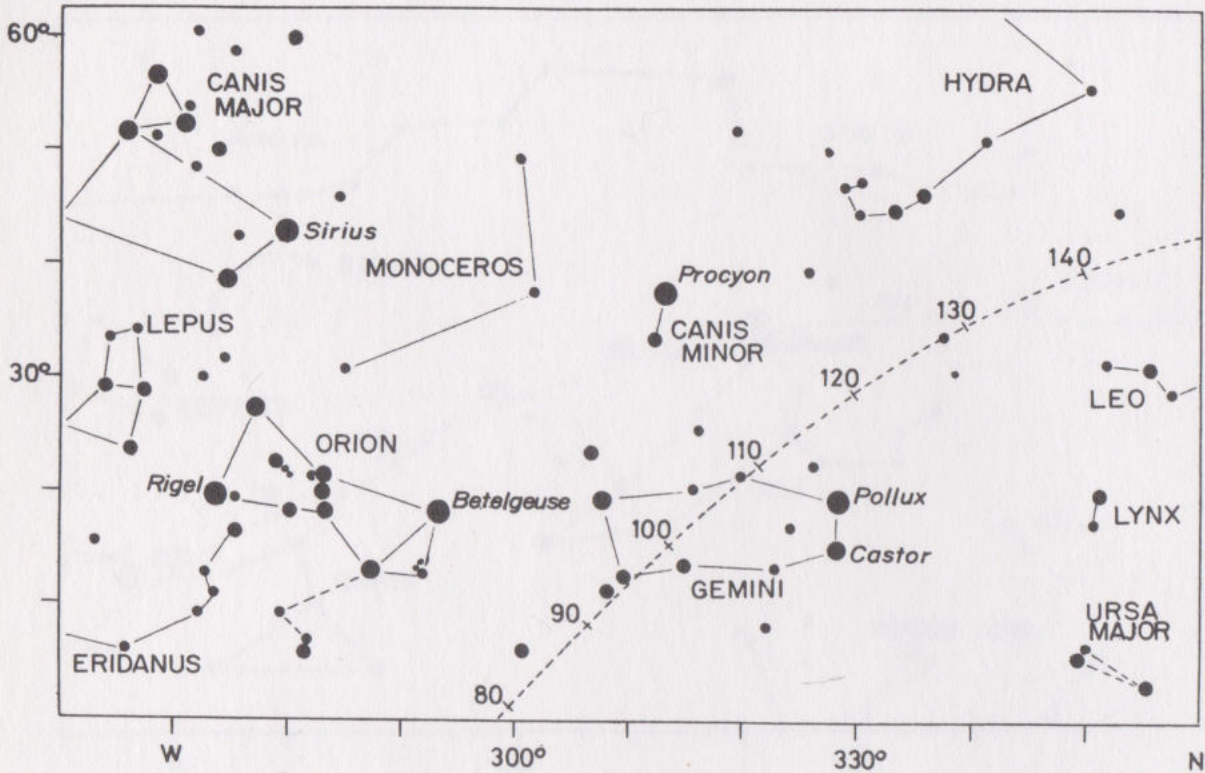
November 21 at 4^h
December 21 at 2^h
January 21 at midnight
February 21 at 22^h
March 21 at 20^h

2R



3L

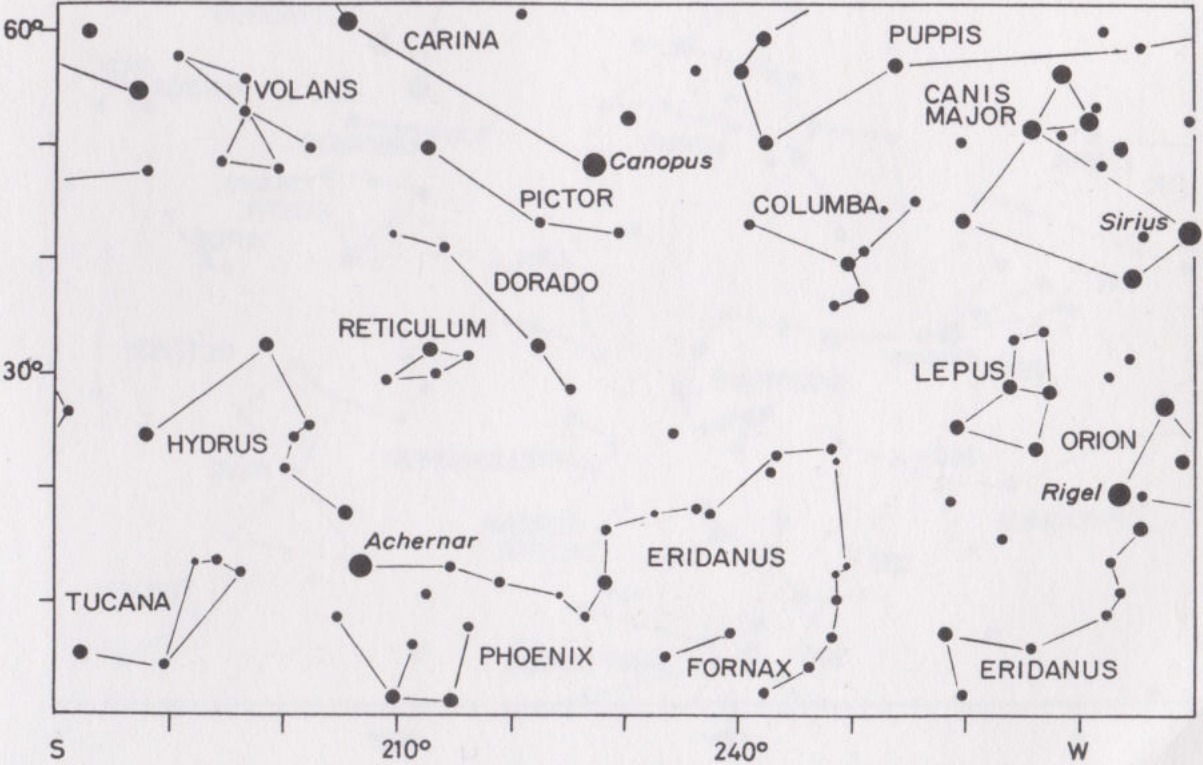
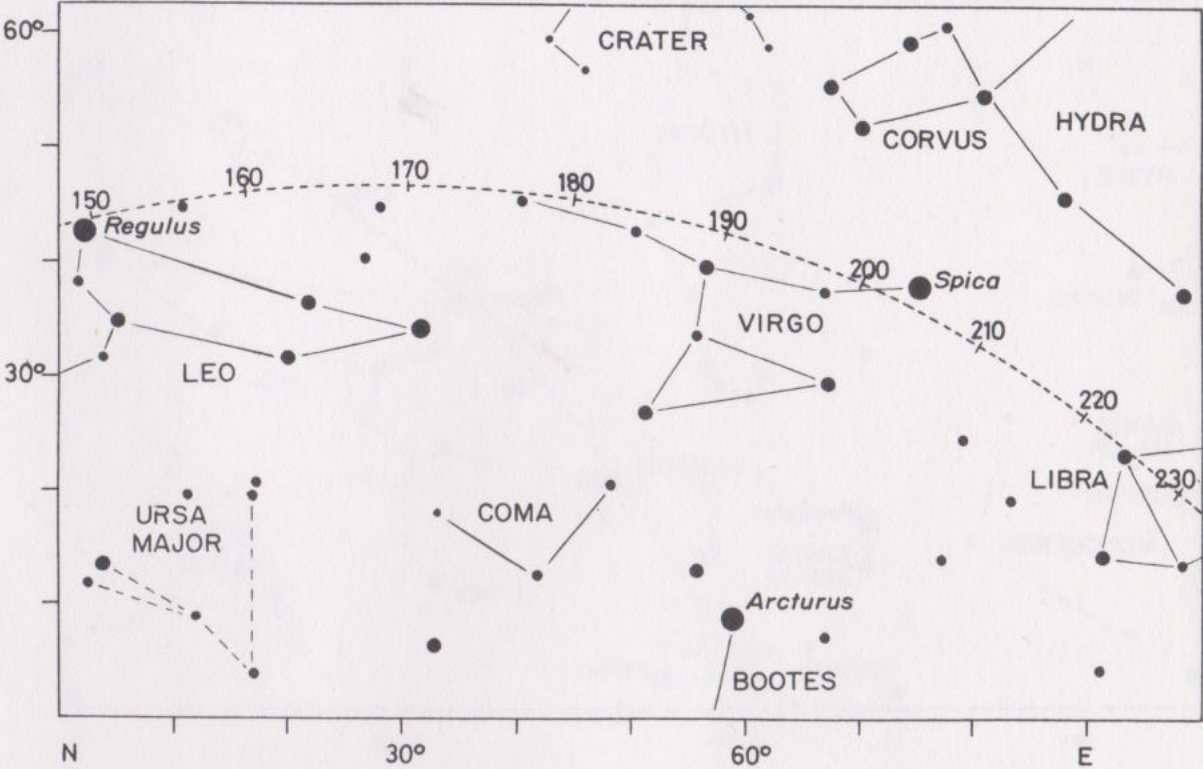
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February 6 at 1 ^h	February 21 at midnight
March 6 at 23 ^h	March 21 at 22 ^h
April 6 at 21 ^h	April 21 at 20 ^h
May 6 at 19 ^h	May 21 at 18 ^h



January 6 at 3^h
February 6 at 1^h
March 6 at 23^h
April 6 at 21^h
May 6 at 19^h

January 21 at 2^h
February 21 at midnight
March 21 at 22^h
April 21 at 20^h
May 21 at 18^h

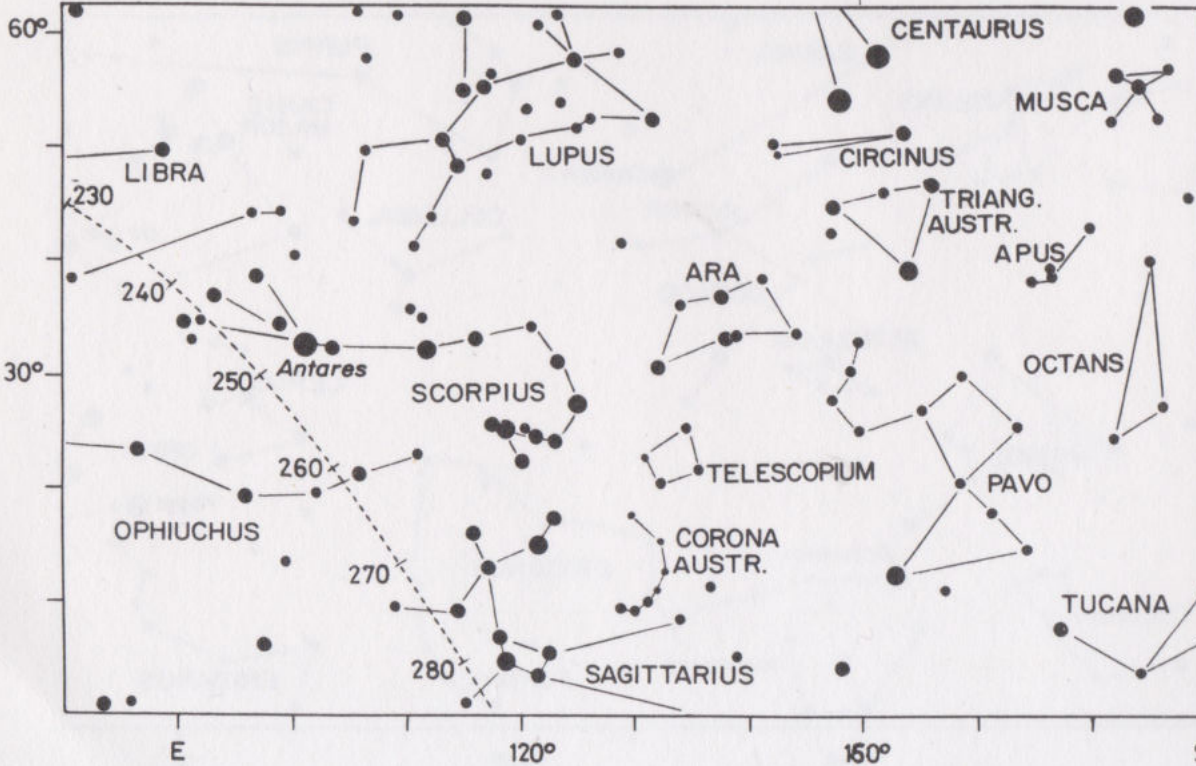
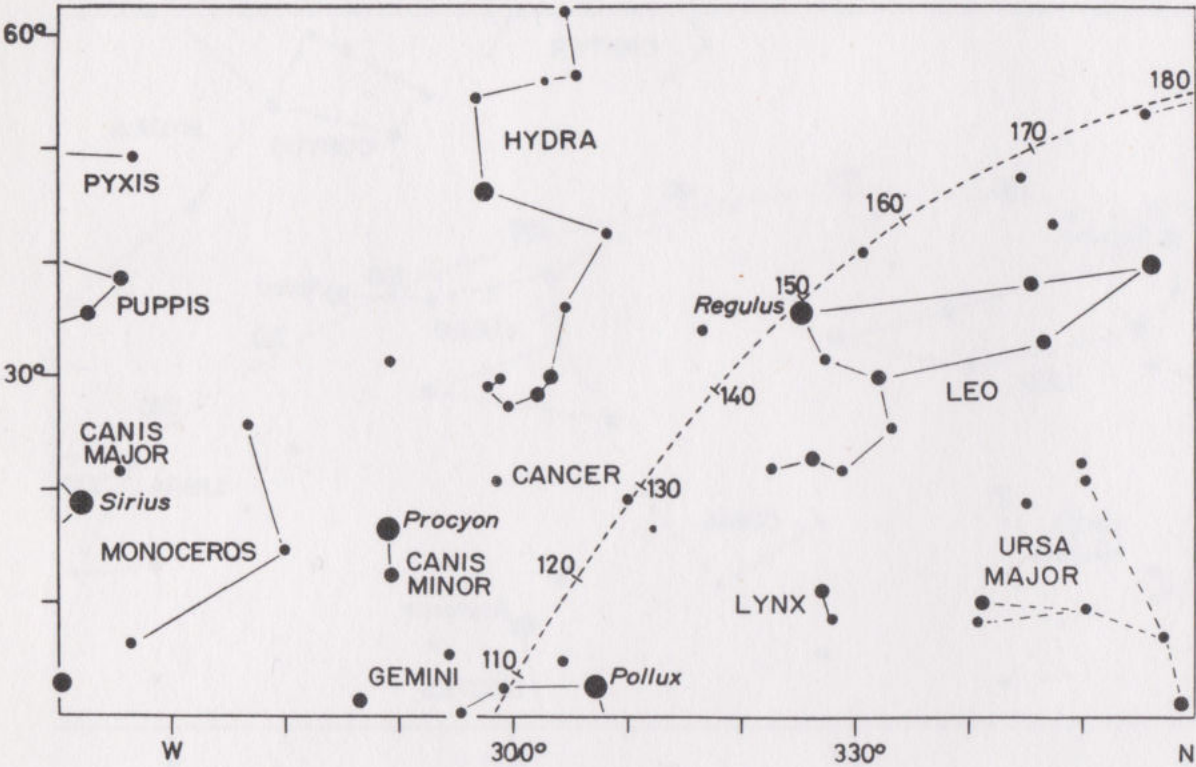
3R



4L

February 6 at 3^h
March 6 at 1^h
April 6 at 23^h
May 6 at 21^h
June 6 at 19^h

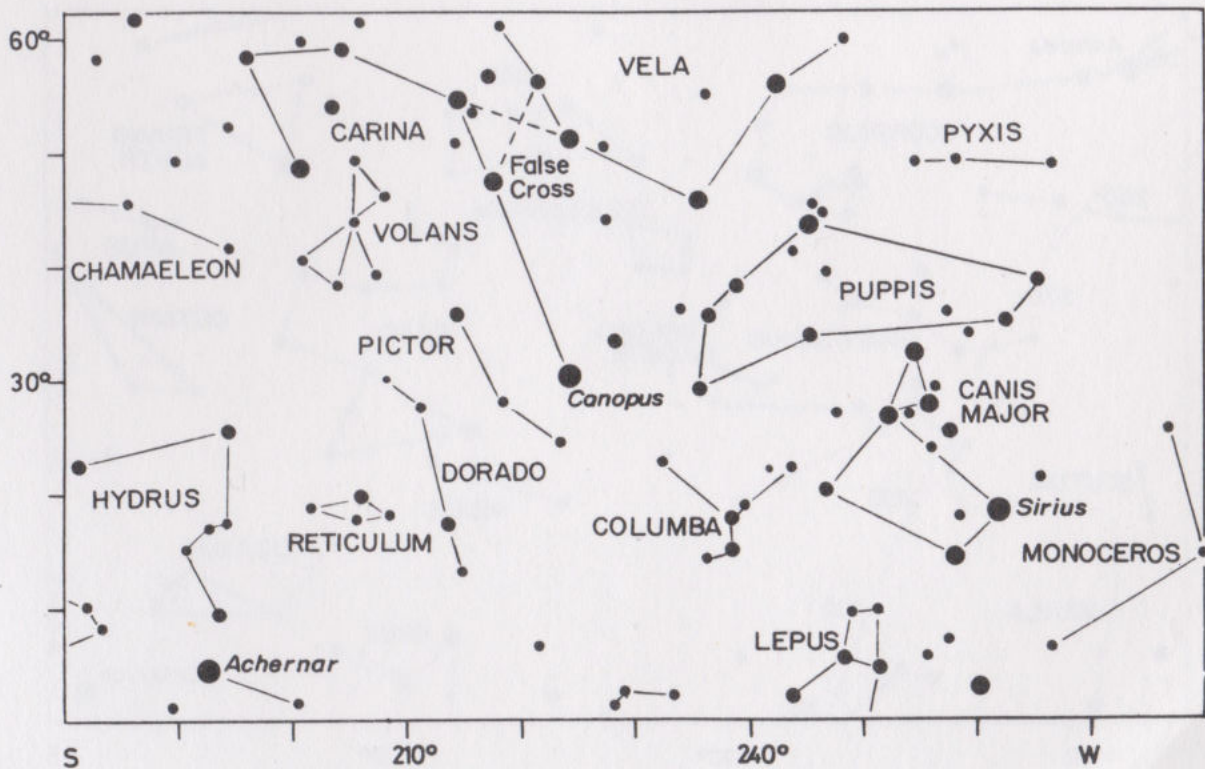
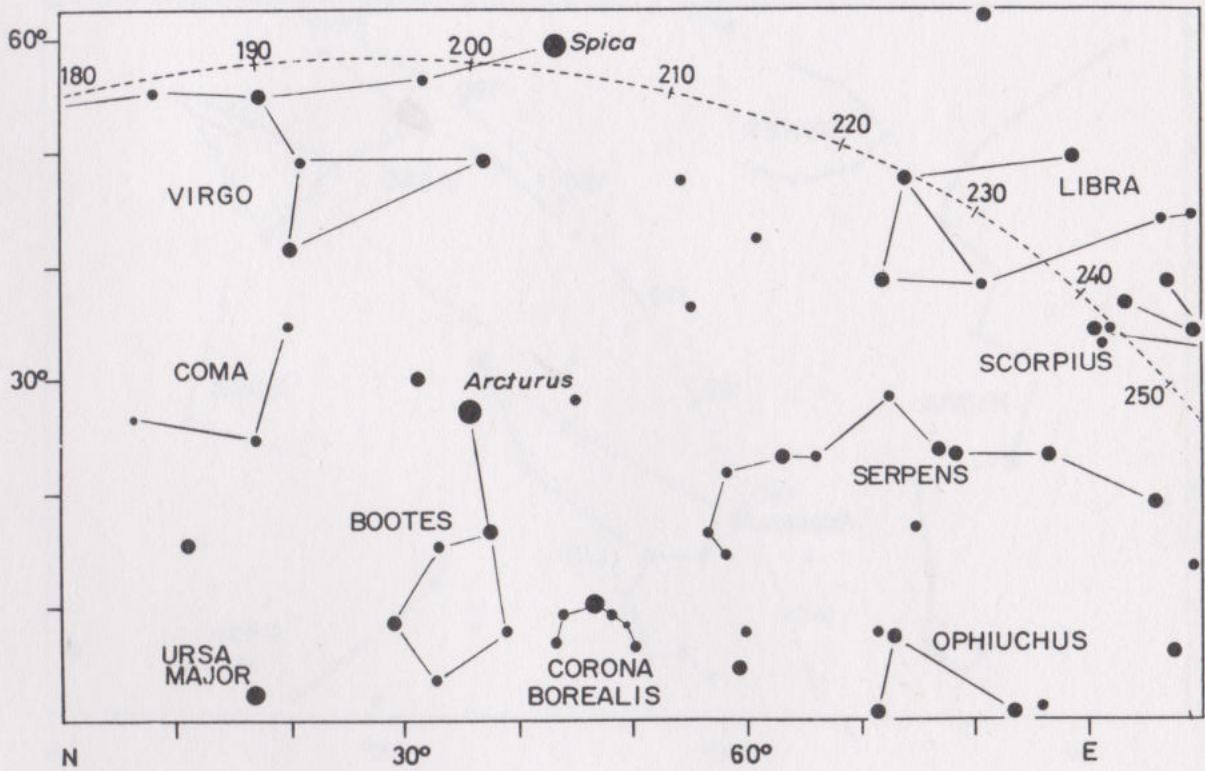
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March 21 at midnight
April 21 at 22^h
May 21 at 20^h
June 21 at 18^h



February 6 at 3^h
 March 6 at 1^h
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 May 6 at 21^h
 June 6 at 19^h

February 21 at 2^h
 March 21 at midnight
 April 21 at 22^h
 May 21 at 20^h
 June 21 at 18^h

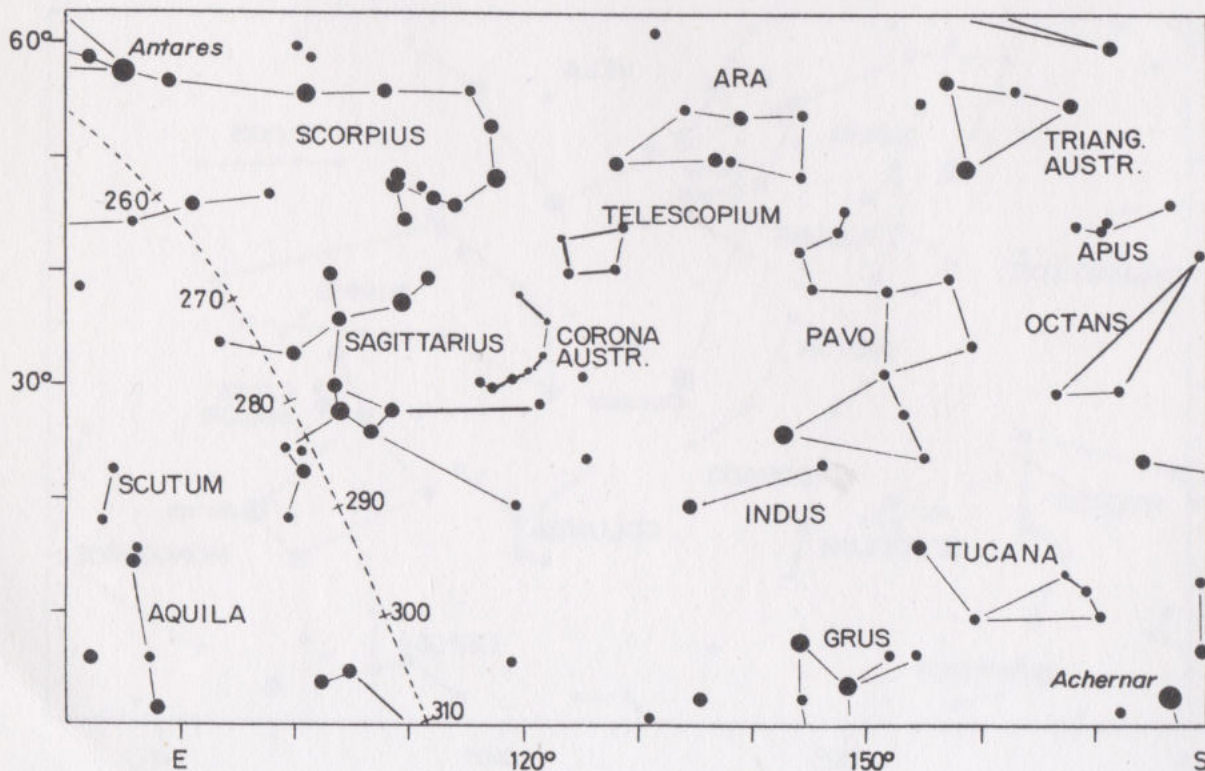
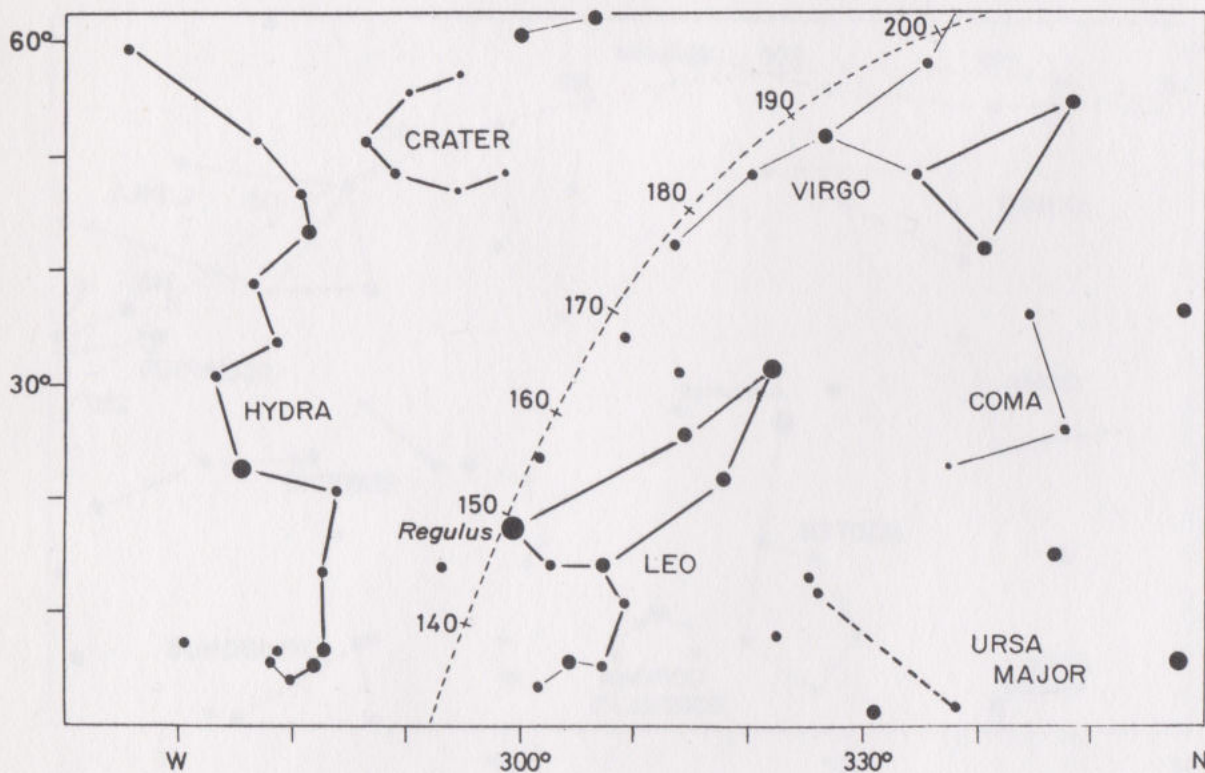
4R



5L

March 6 at 3^h
 April 6 at 1^h
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 June 6 at 21^h
 July 6 at 19^h

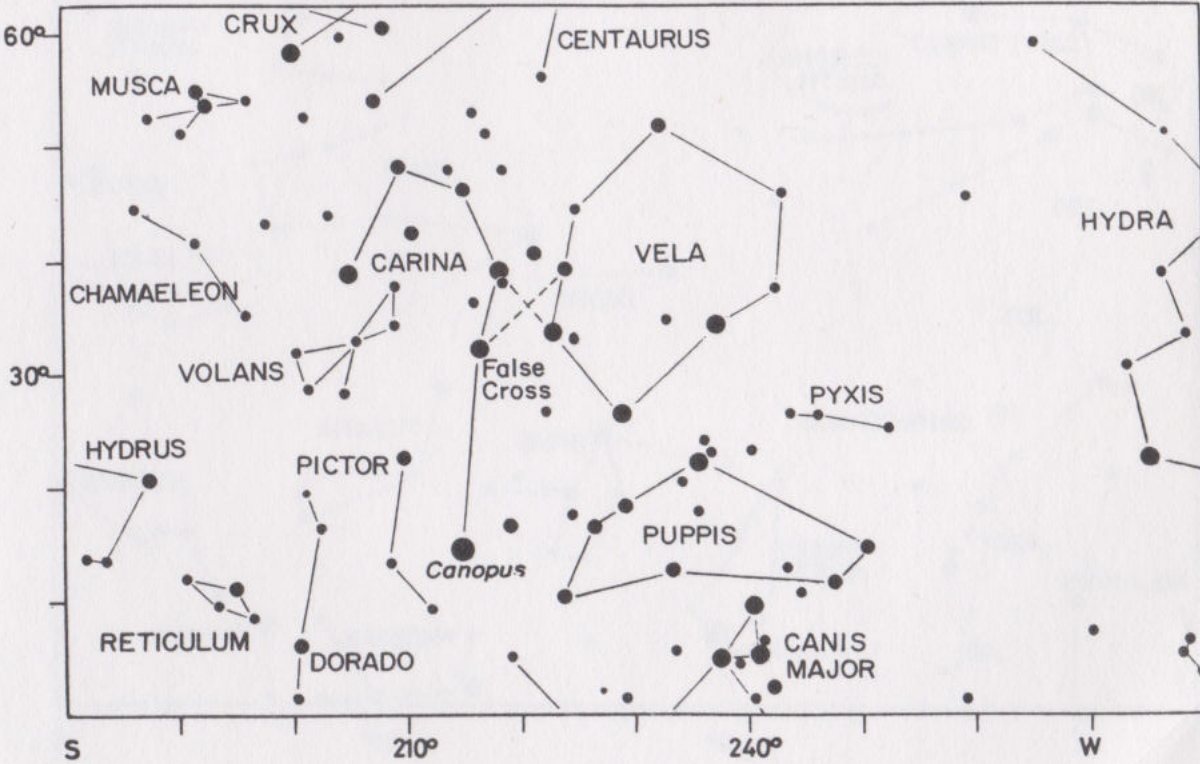
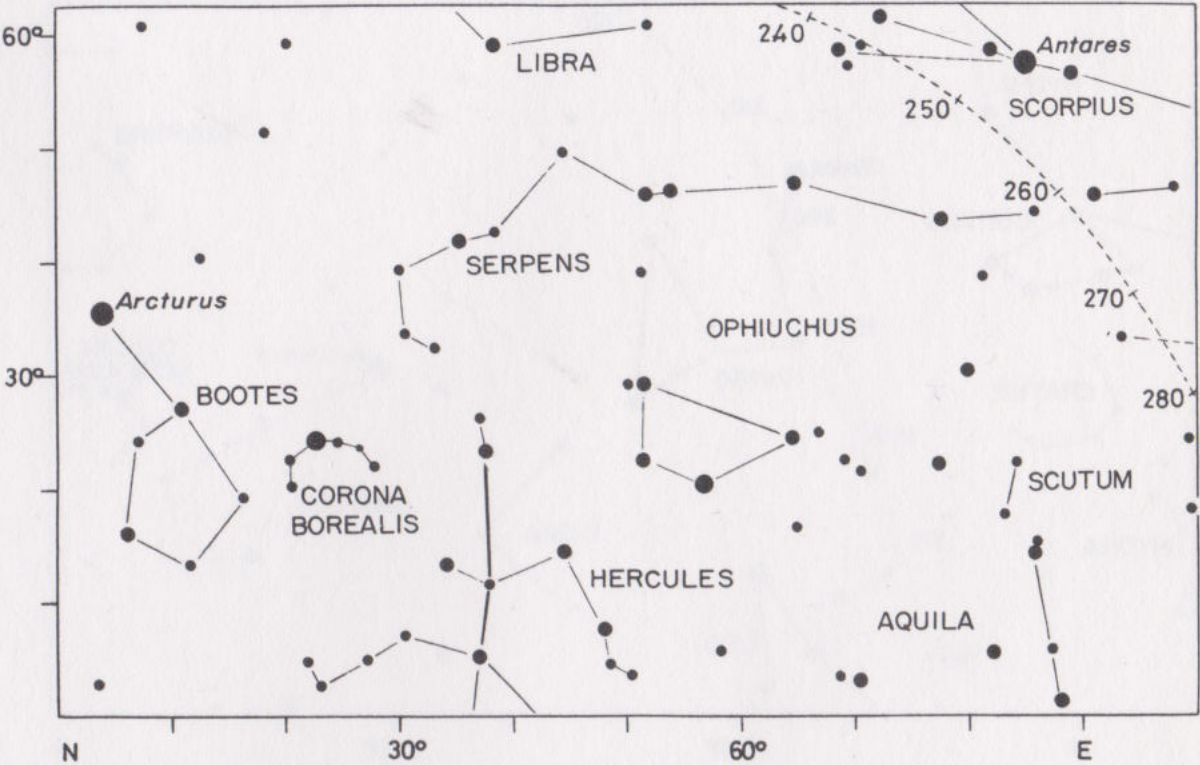
March 21 at 2^h
 April 21 at midnight
 May 21 at 22^h
 June 21 at 20^h
 July 21 at 18^h



March 6 at 3^h
April 6 at 1^h
May 6 at 23^h
June 6 at 21^h
July 6 at 19^h

March 21 at 2ⁿ
April 21 at midnight
May 21 at 22^h
June 21 at 20^h
July 21 at 18^h

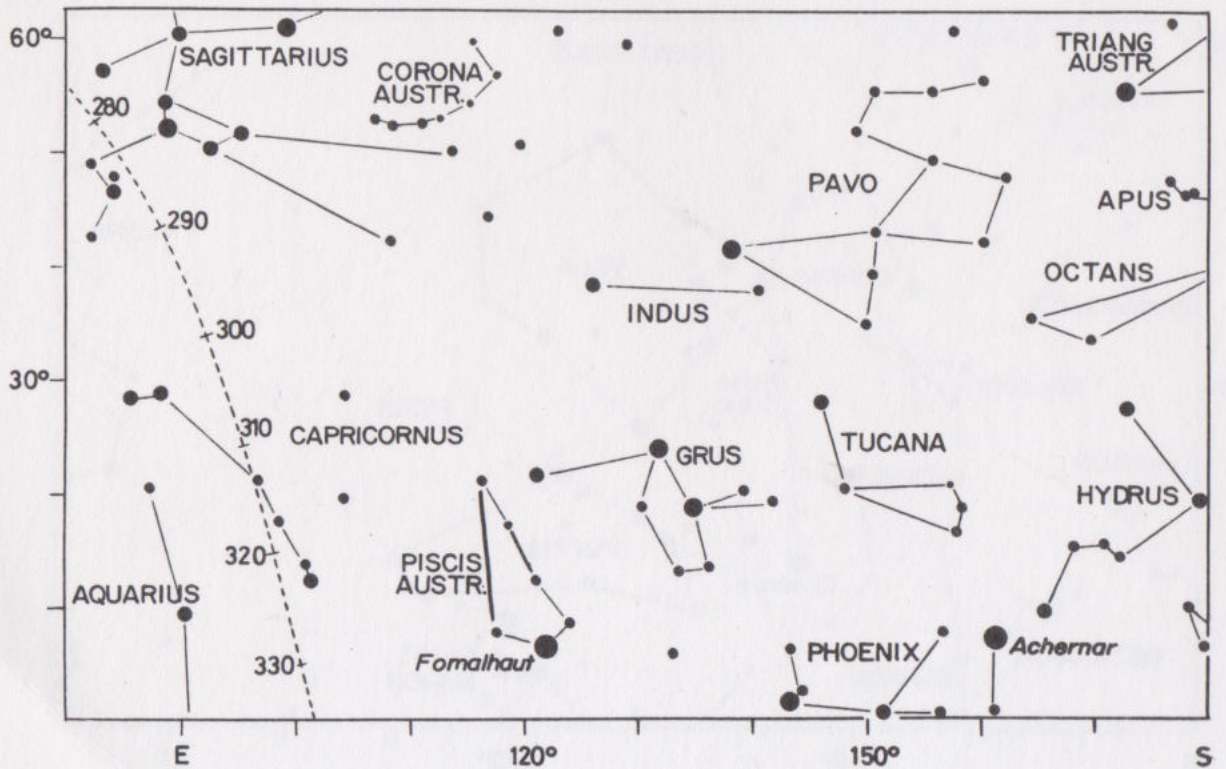
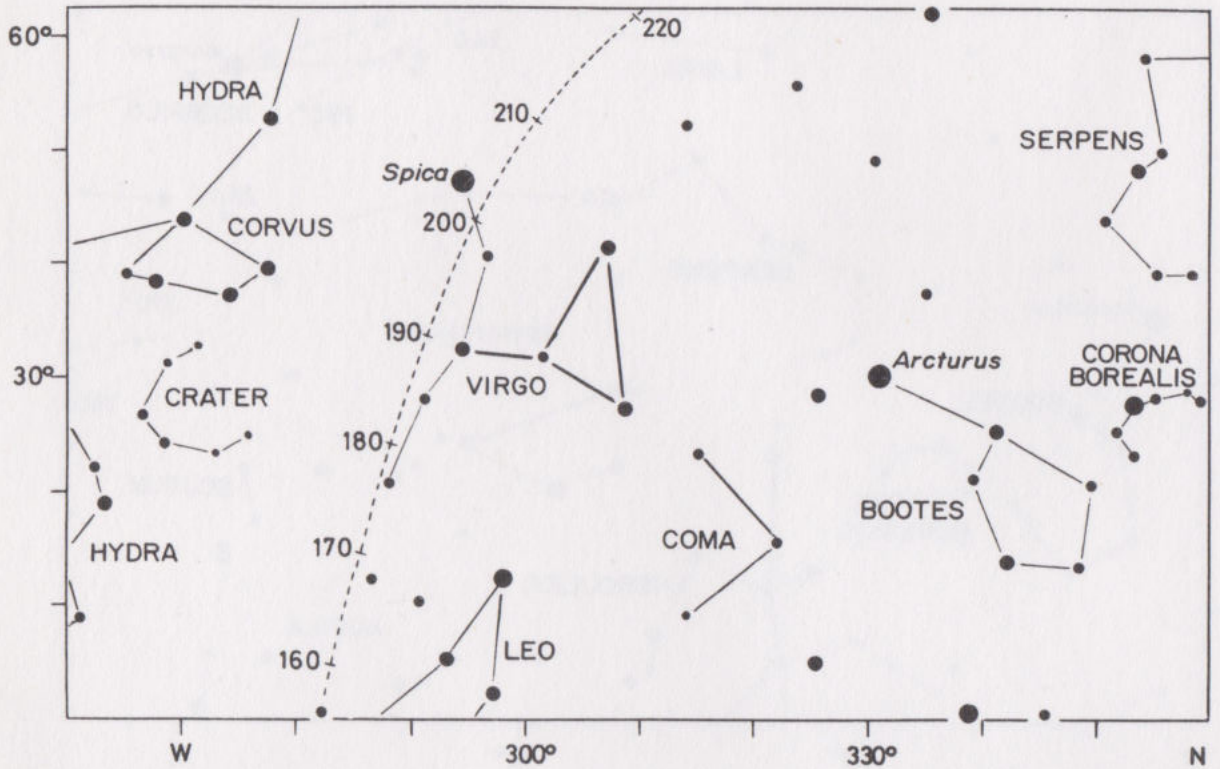
5R



6L

March 6 at 5^h
April 6 at 3^h
May 6 at 1^h
June 6 at 23^h
July 6 at 21^h

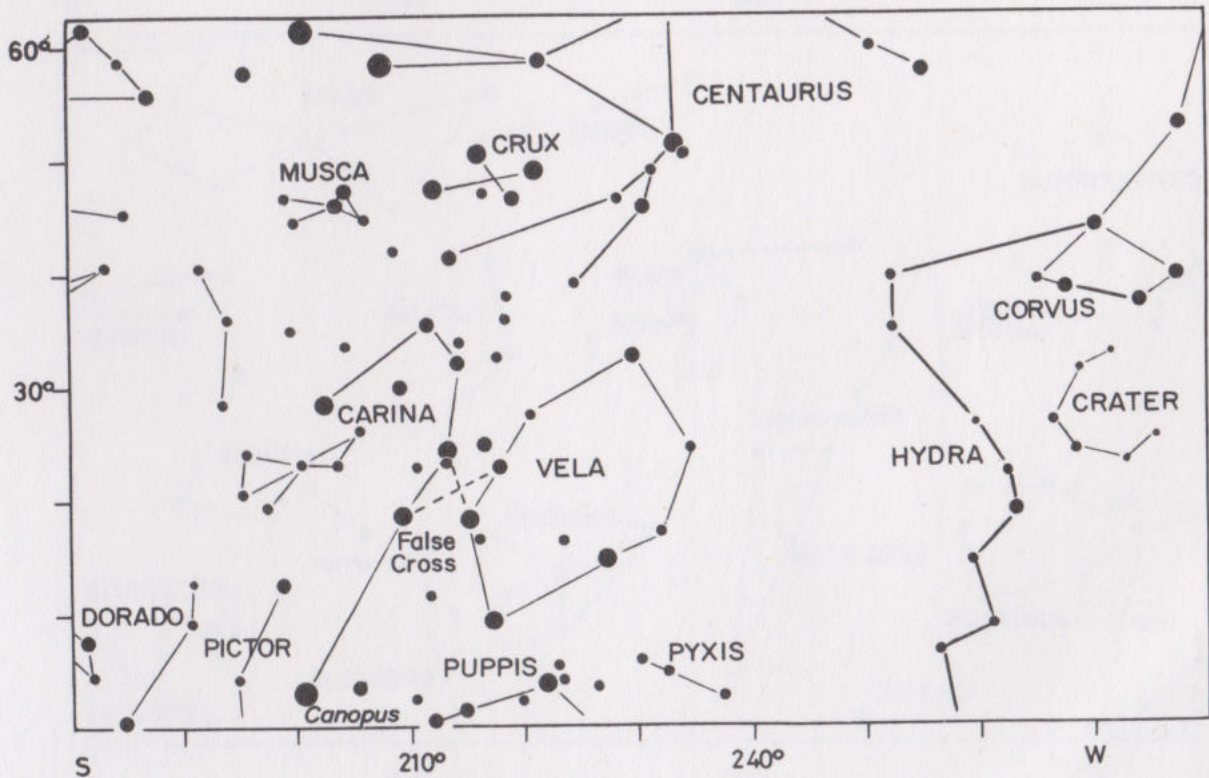
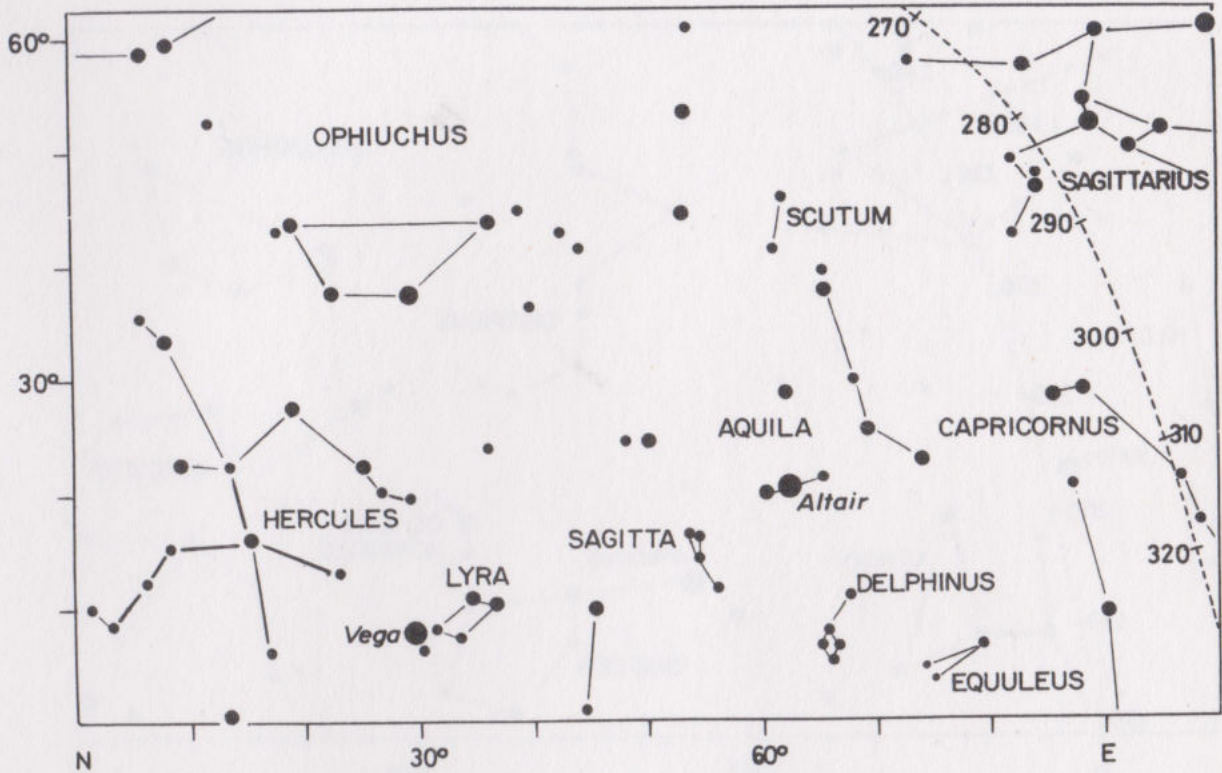
March 21 at 4ⁿ
April 21 at 2^h
May 21 at midnight
June 21 at 22^h
July 21 at 20^h



March 6 at 5^h
 April 6 at 3^h
 May 6 at 1^h
 June 6 at 23^h
 July 6 at 21^h

March 21 at 4^h
 April 21 at 2^h
 May 21 at midnight
 June 21 at 22^h
 July 21 at 20^h

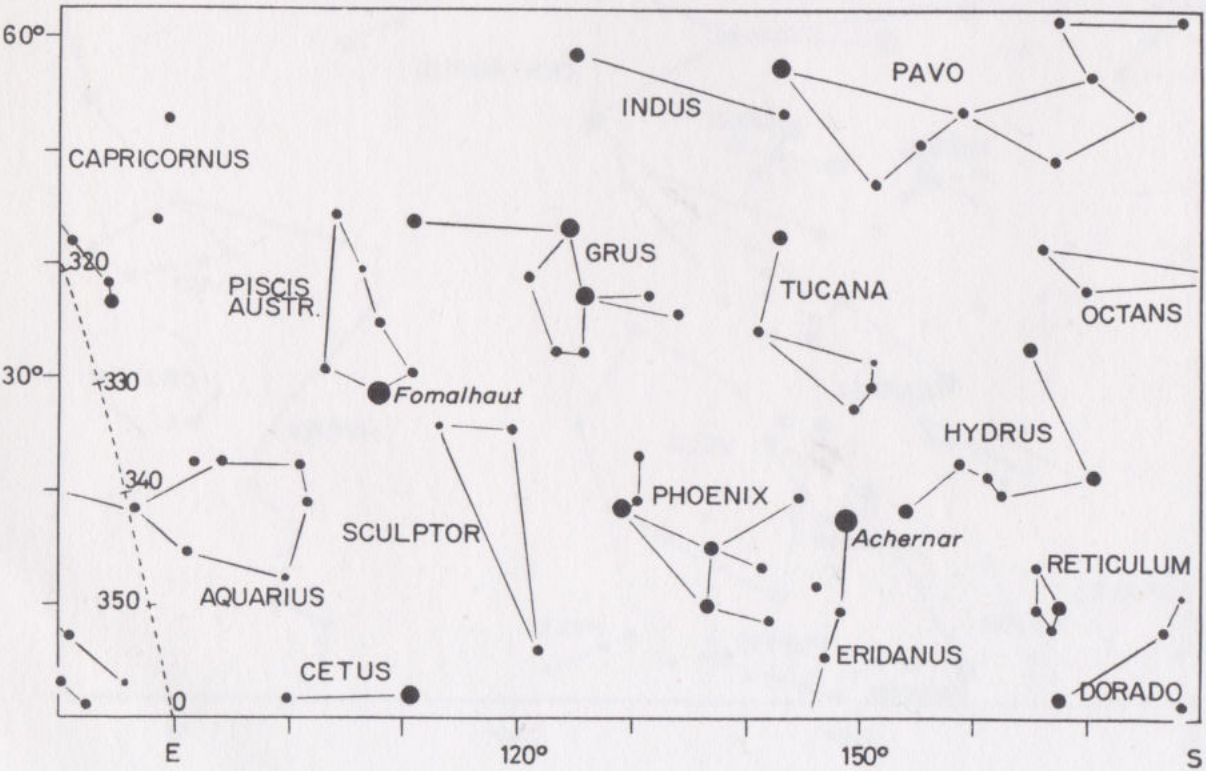
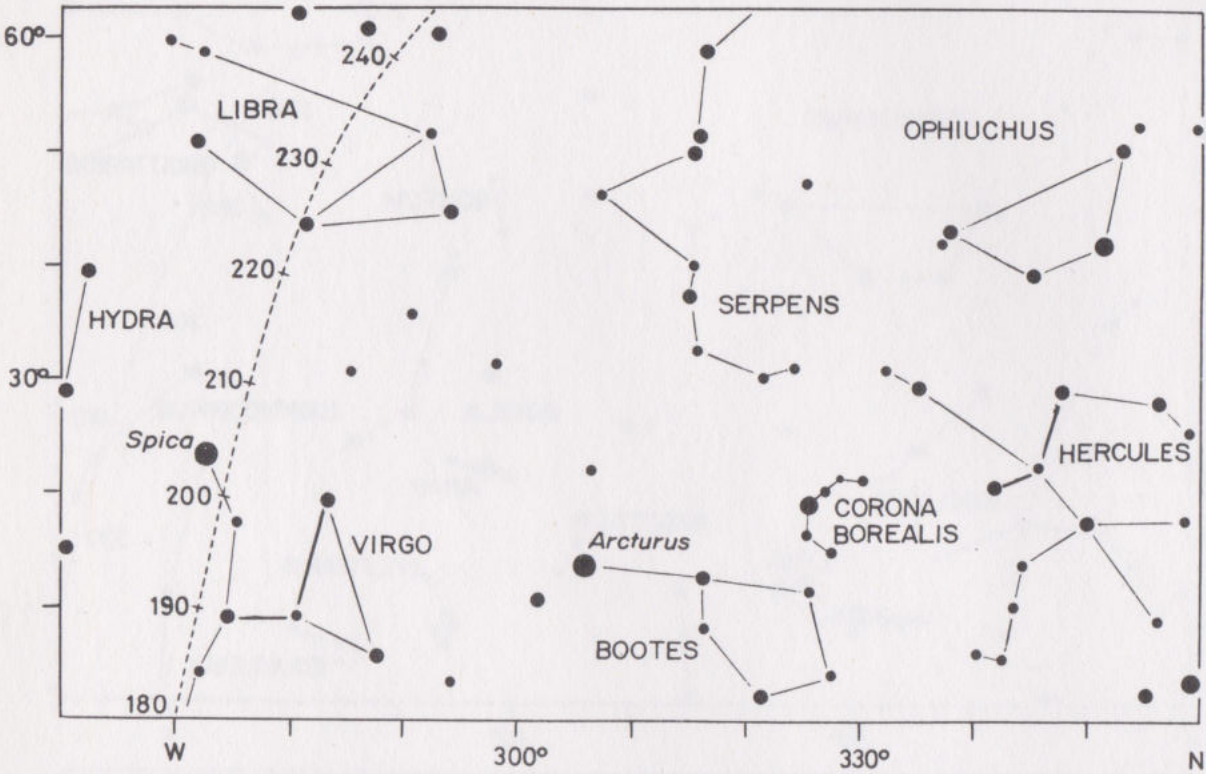
6R



7L

April 6 at 5^h
May 6 at 3^h
June 6 at 1^h
July 6 at 23^h
August 6 at 21^h

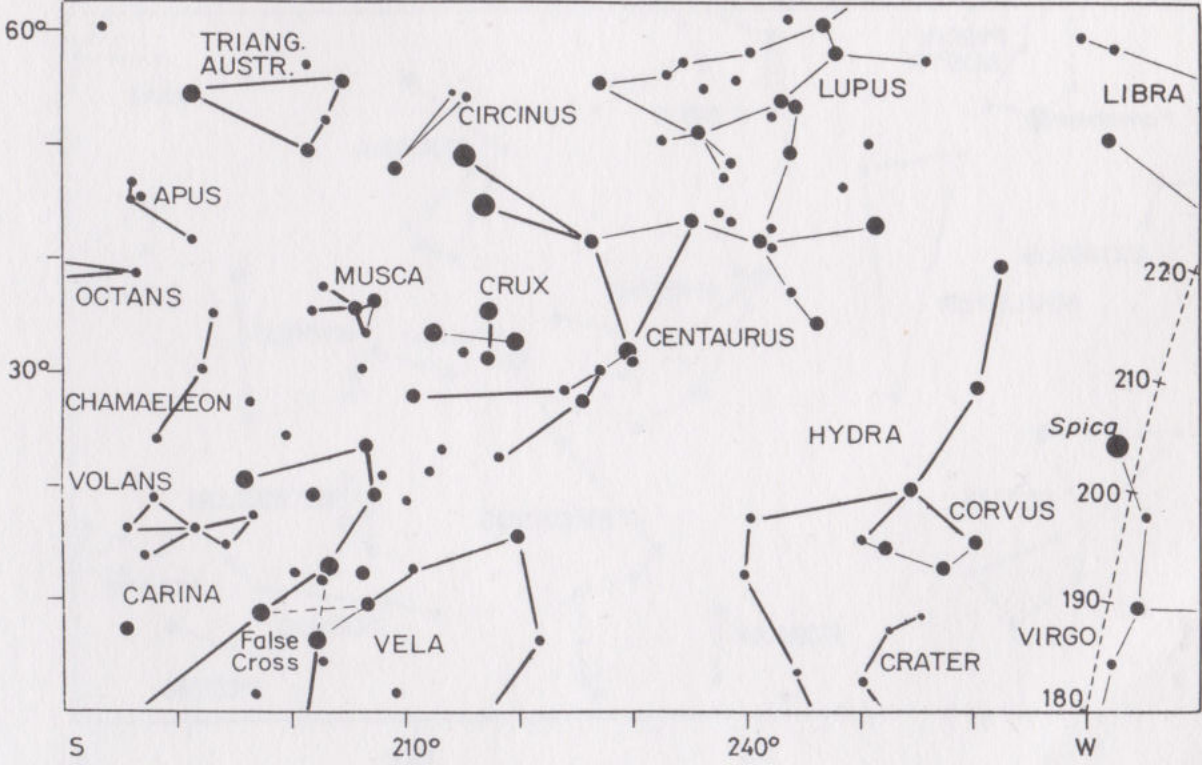
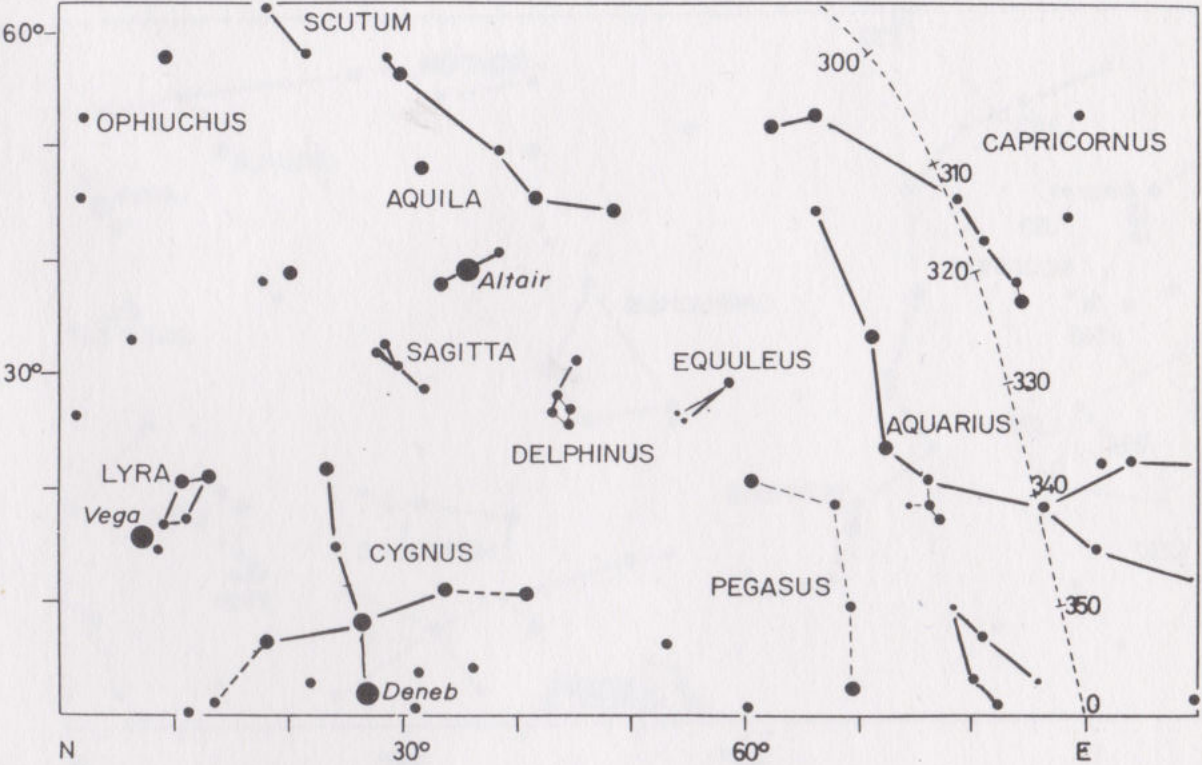
April 21 at 4^h
May 21 at 2^h
June 21 at midnight
July 21 at 22^h
August 21 at 20^h



April 6 at 5^h
May 6 at 3^h
June 6 at 1^h
July 6 at 23^h
August 6 at 21^h

April 21 at 4^h
May 21 at 2^h
June 21 at midnight
July 21 at 22^h
August 21 at 20^h

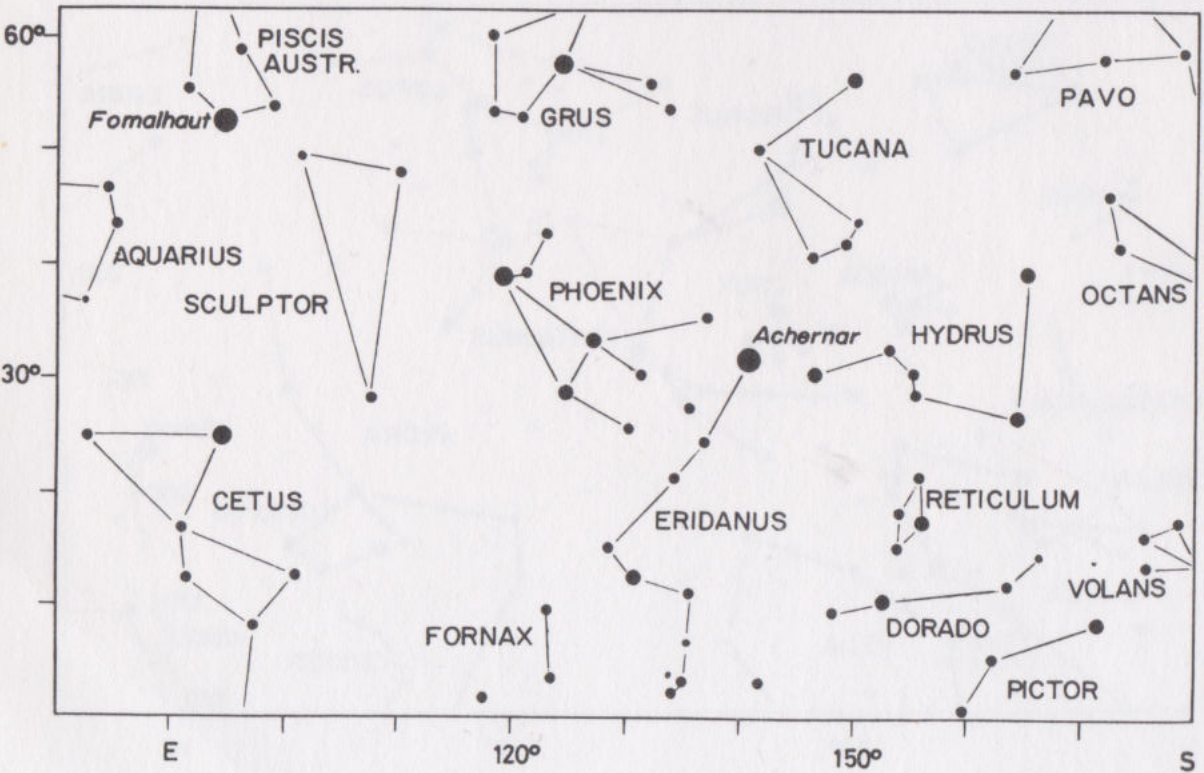
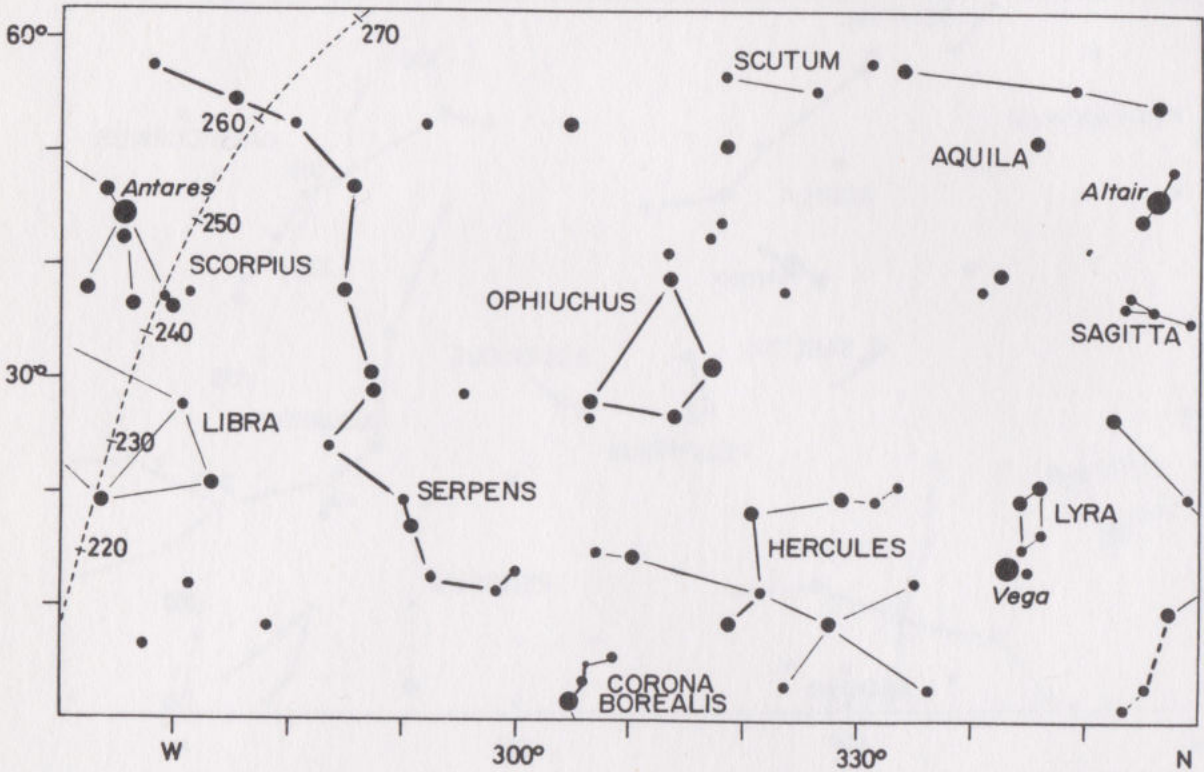
7R



8L

May 6 at 5^h
June 6 at 3^h
July 6 at 1^h
August 6 at 23^h
September 6 at 21^h

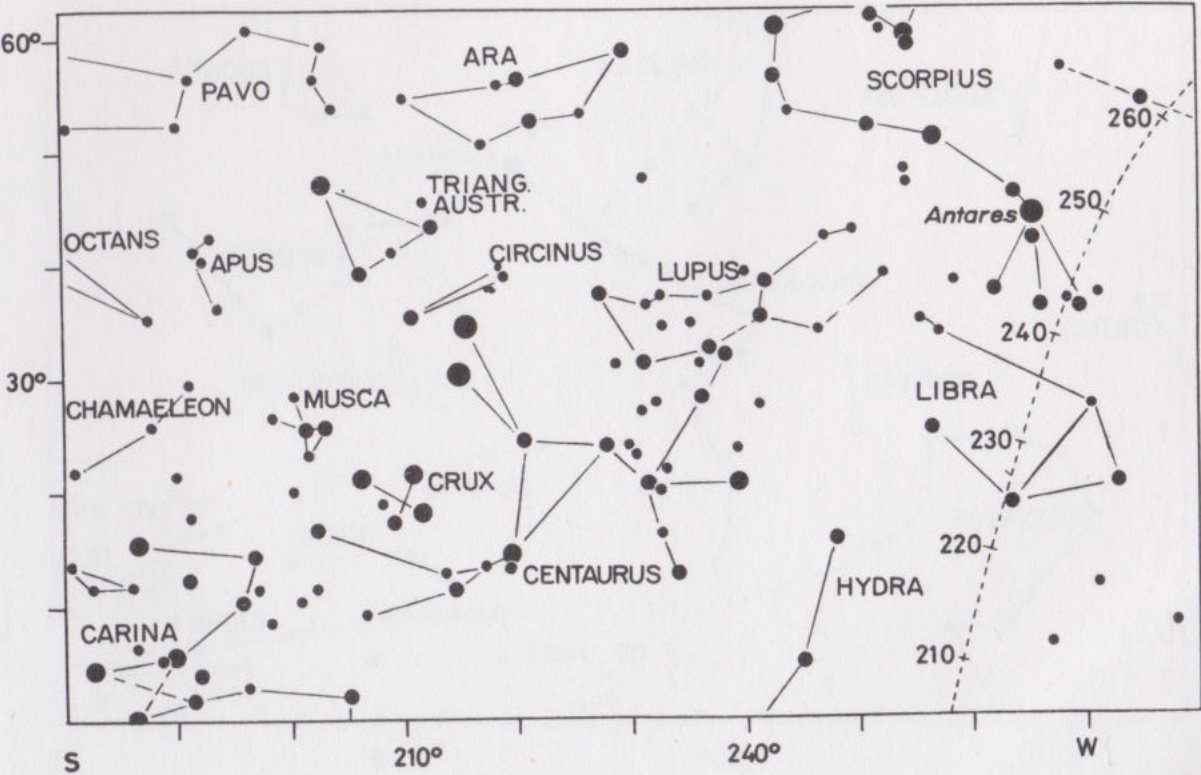
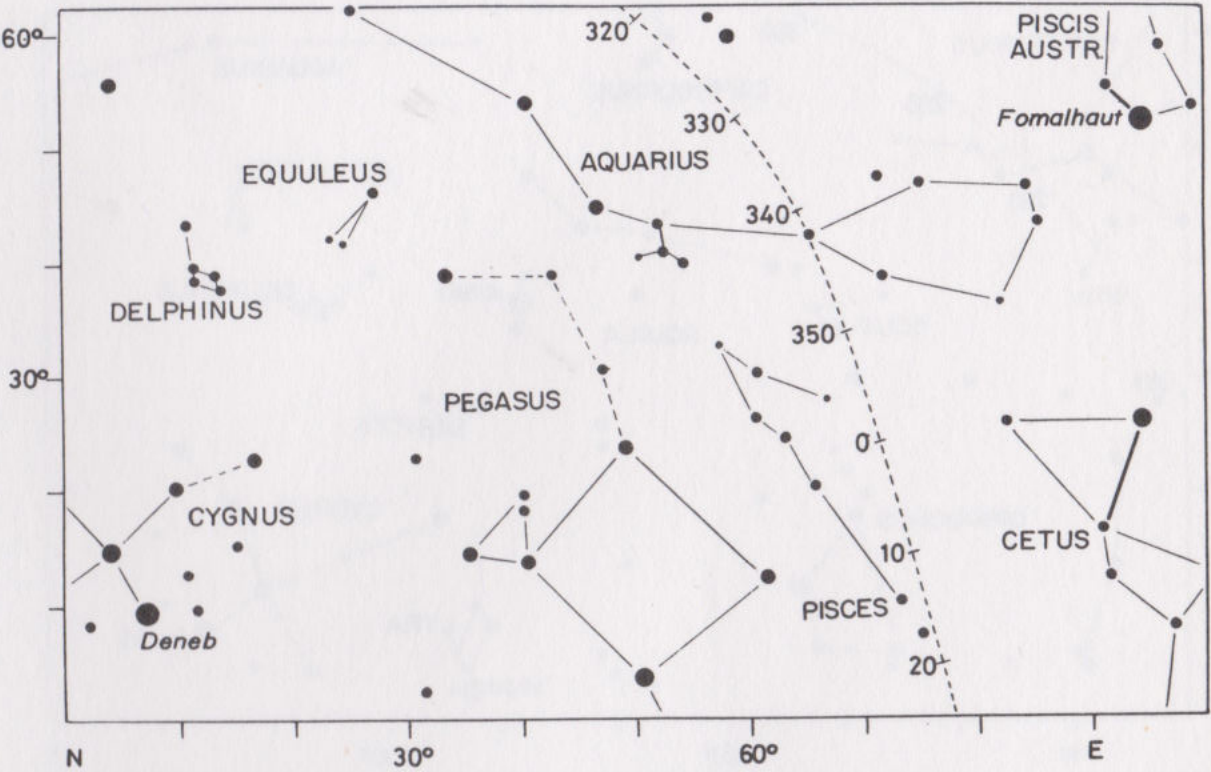
May 21 at 4^h
June 21 at 2^h
July 21 at midnight
August 21 at 22^h
September 21 at 20^h



May 6 at 5^h
June 6 at 3^h
July 6 at 1^h
August 6 at 23^h
September 6 at 21^h

May 21 at 4^h
June 21 at 2^h
July 21 at midnight
August 21 at 22^h
September 21 at 20^h

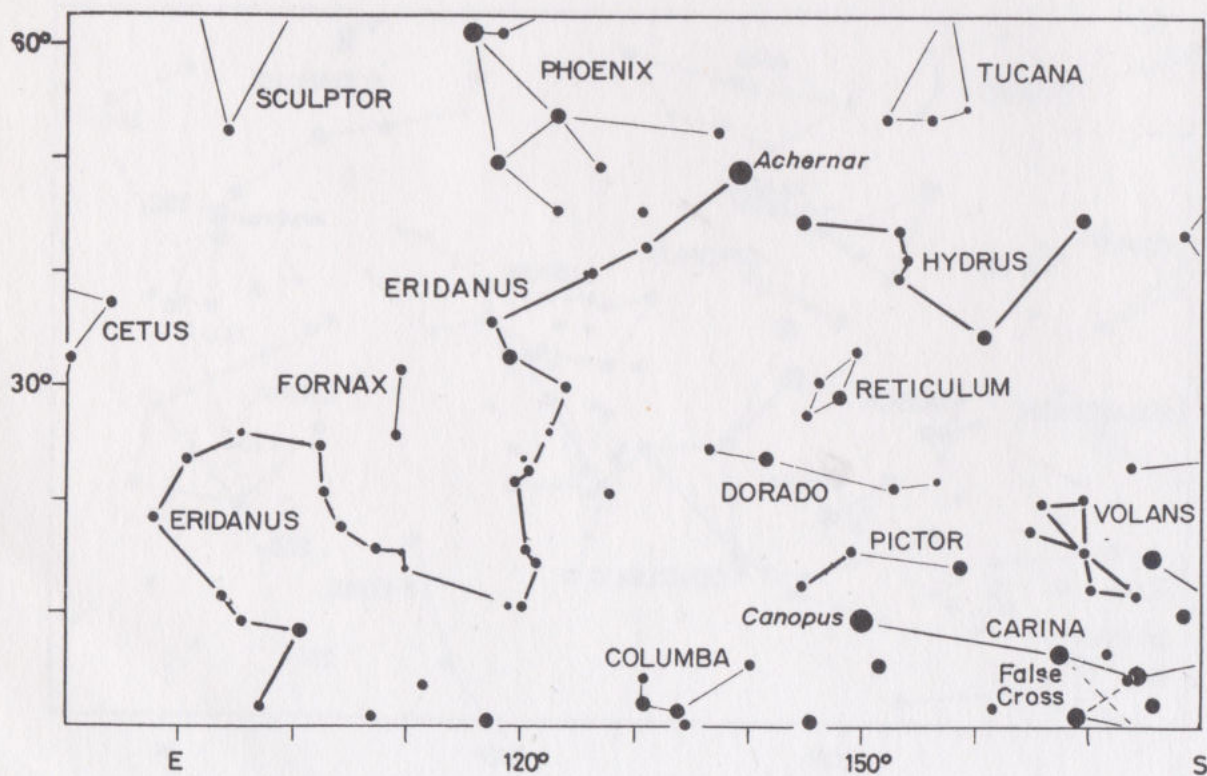
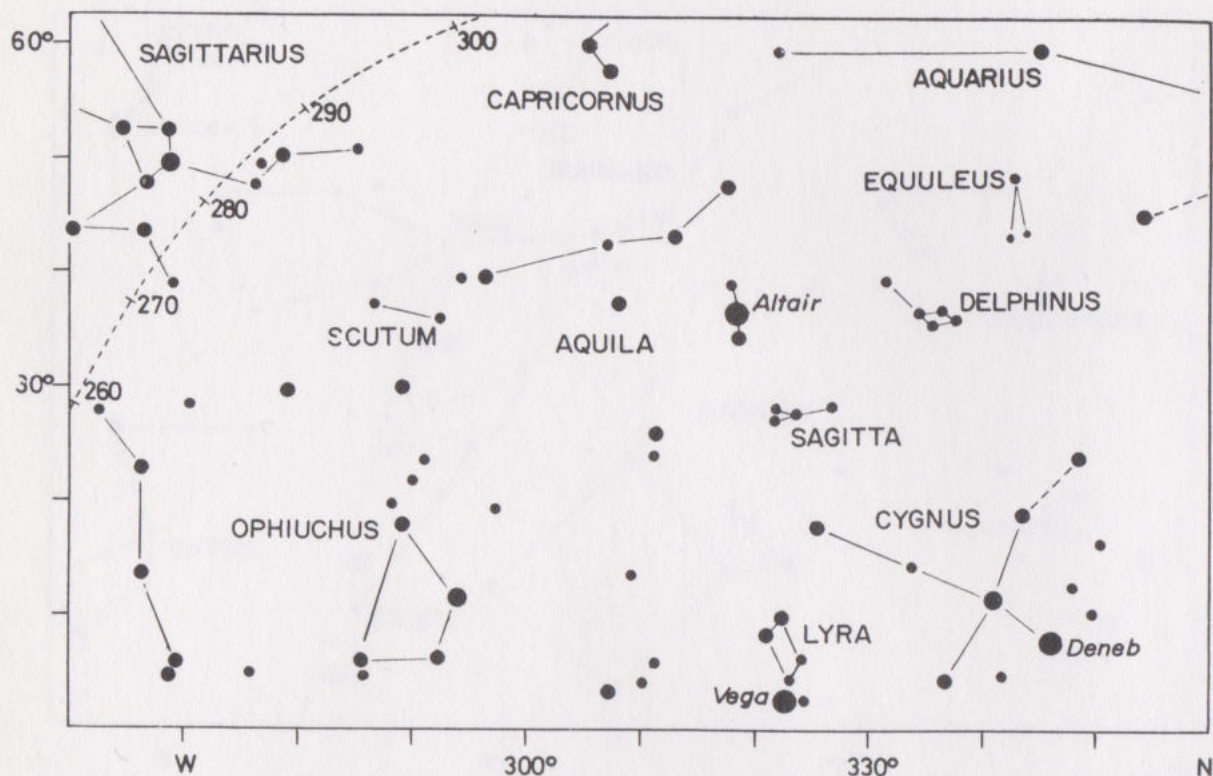
8R



9L

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 August 6 at 1^h
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 October 6 at 21^h

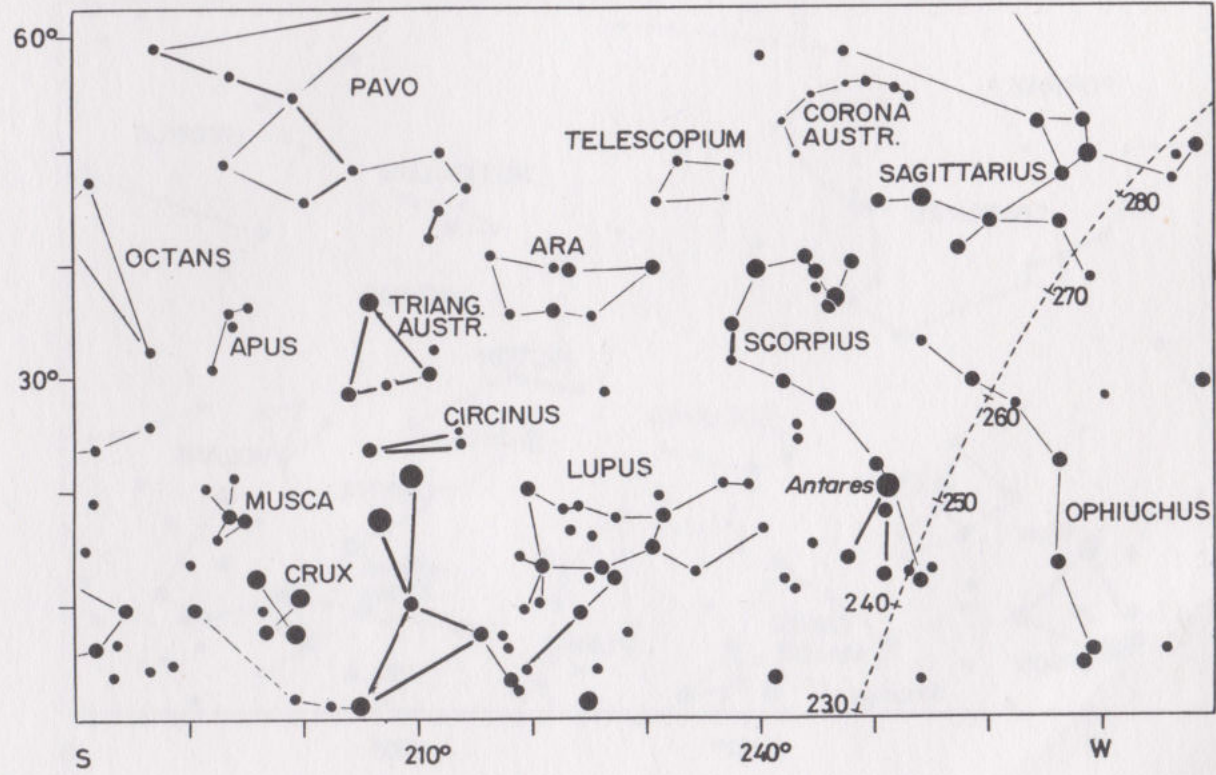
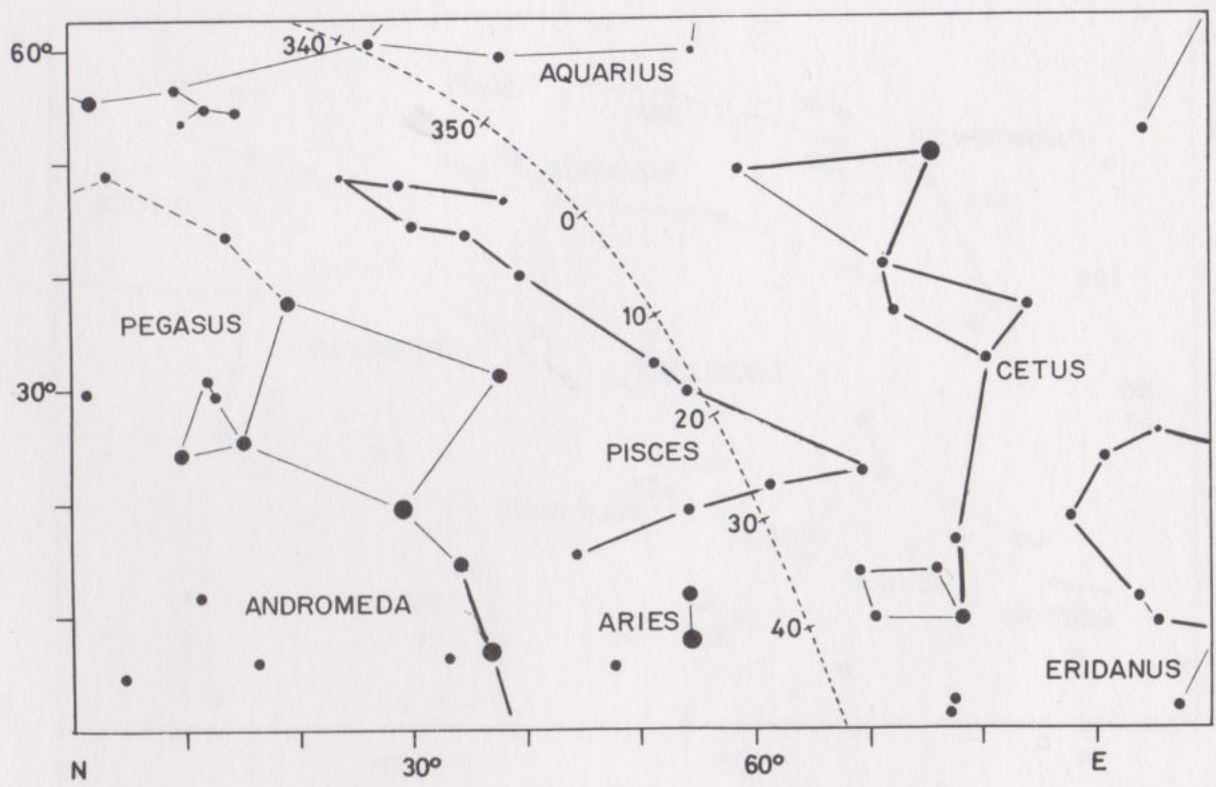
June 21 at 4^h
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 August 21 at midnight
 September 21 at 22^h
 October 21 at 20^h



June 6 at 5^h
July 6 at 3^h
August 6 at 1^h
September 6 at 23^h
October 6 at 21^h

June 21 at 4^h
July 21 at 2^h
August 21 at midnight
September 21 at 22^h
October 21 at 20^h

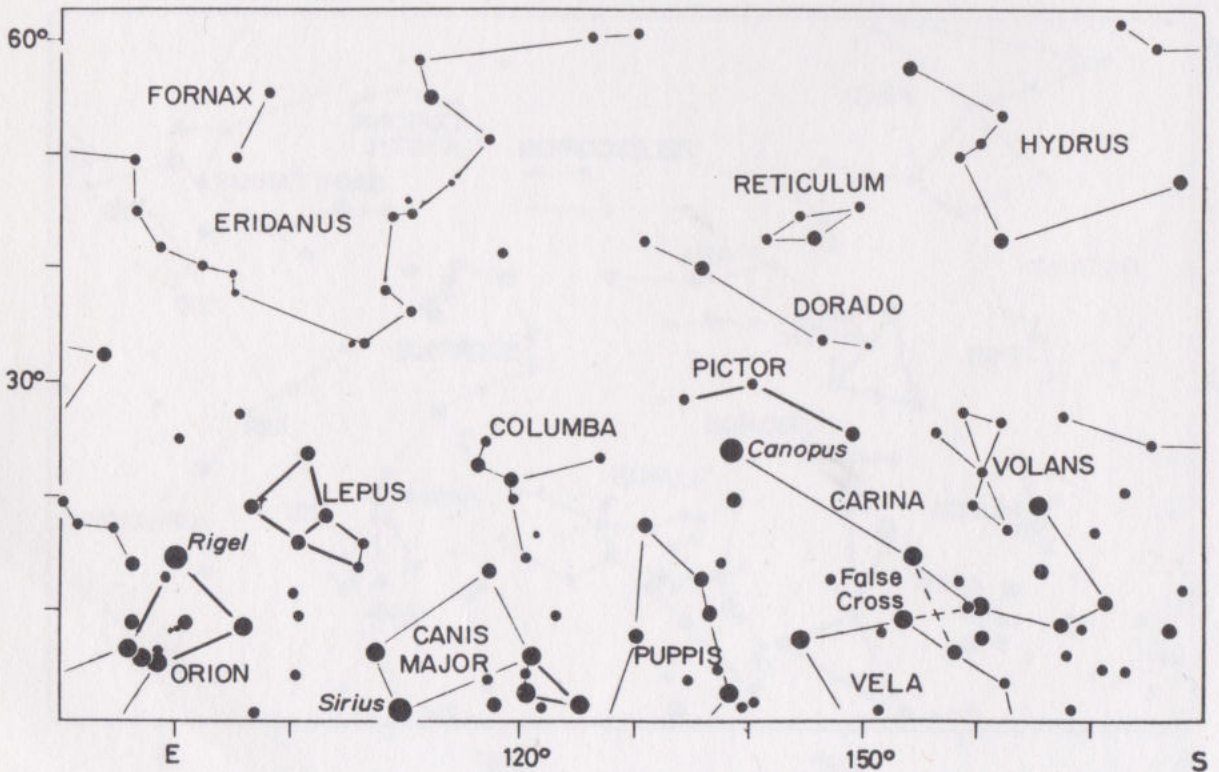
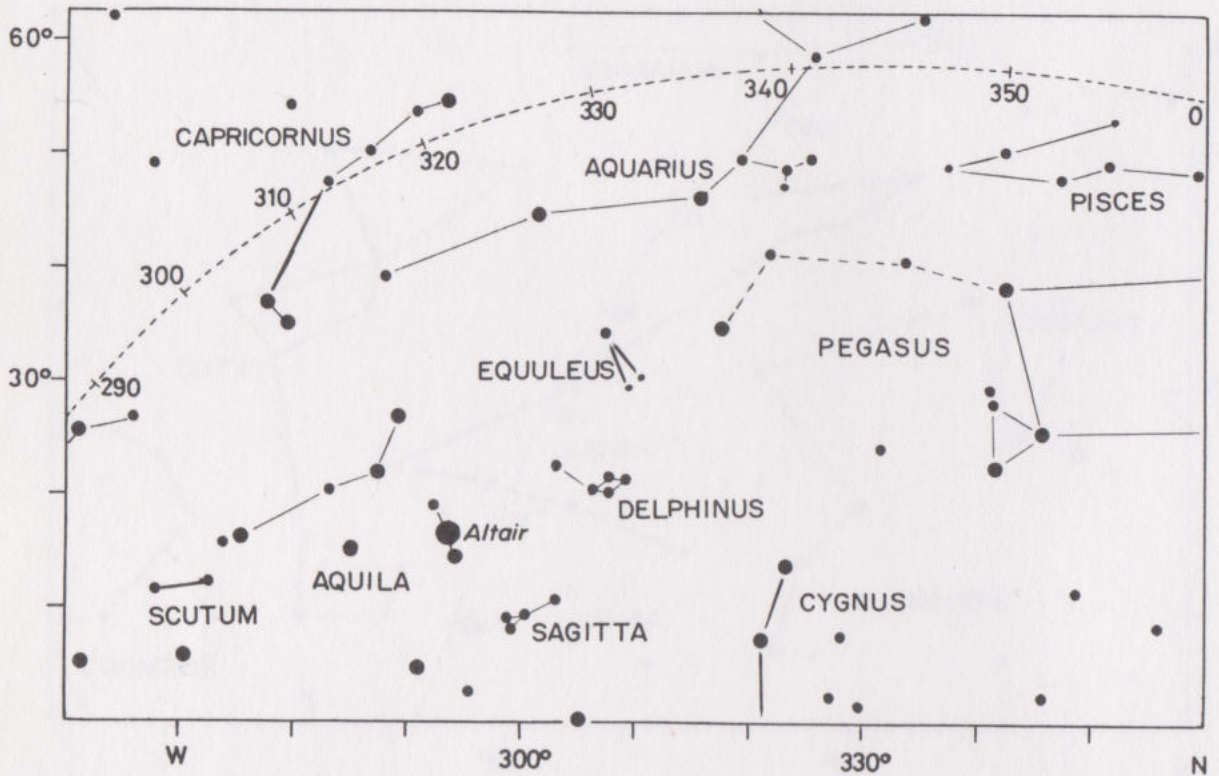
9R



10L

July 6 at 5^h
August 6 at 3^h
September 6 at 1^h
October 6 at 23^h
November 6 at 21^h

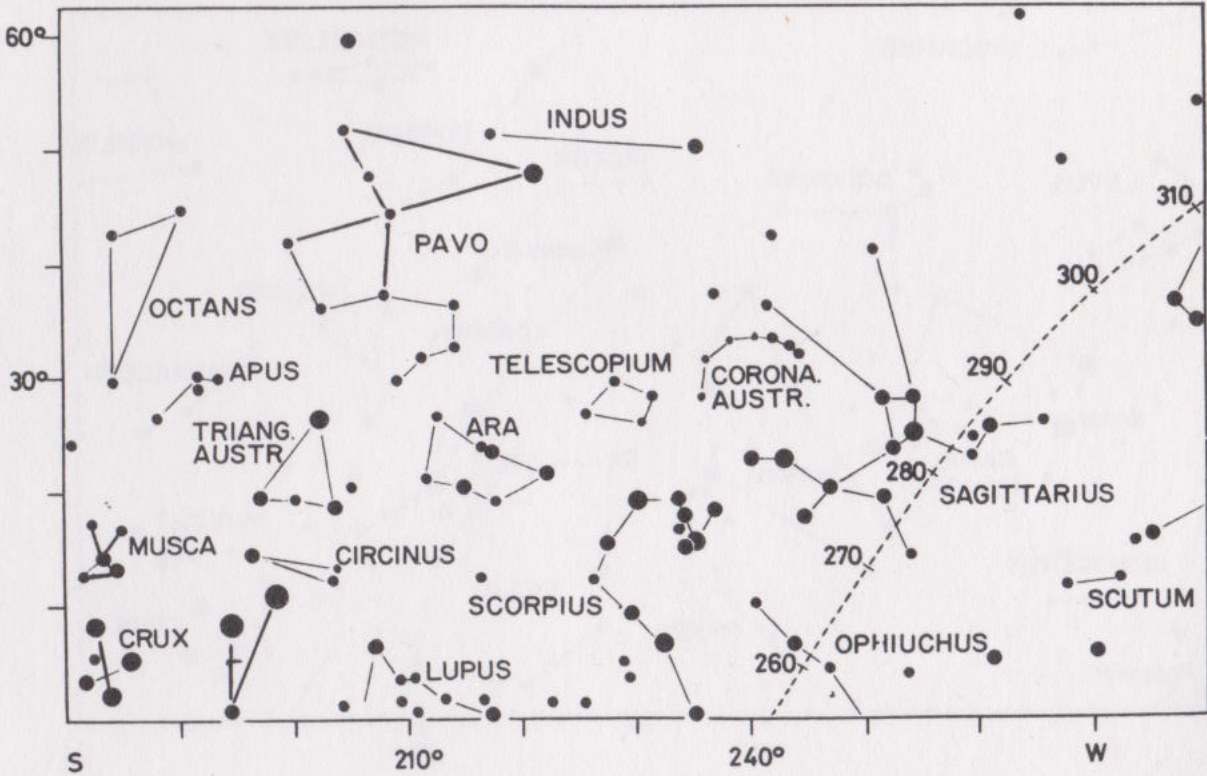
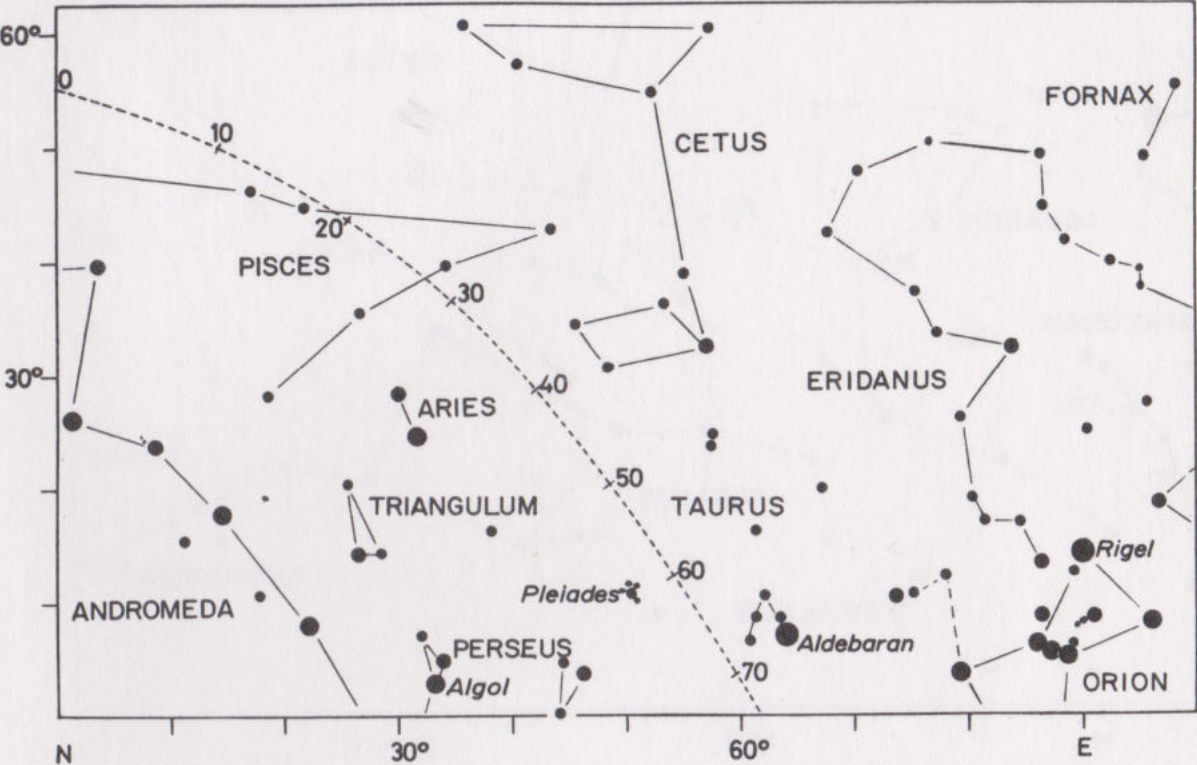
July 21 at 4^h
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October 21 at 22^h
November 21 at 20^h



July 6 at 5^h
August 6 at 3^h
September 6 at 1^h
October 6 at 23^h
November 6 at 21^h

July 21 at 4^h
August 21 at 2^h
September 21 at midnight
October 21 at 22^h
November 21 at 20^h

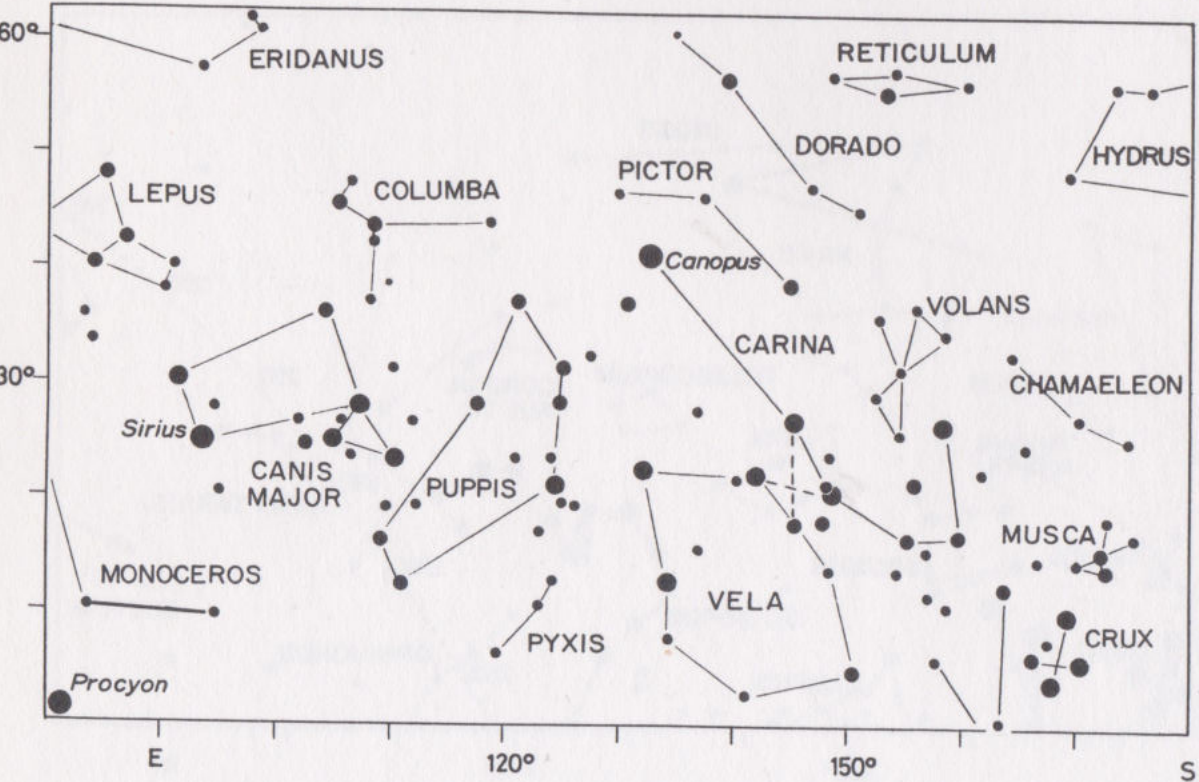
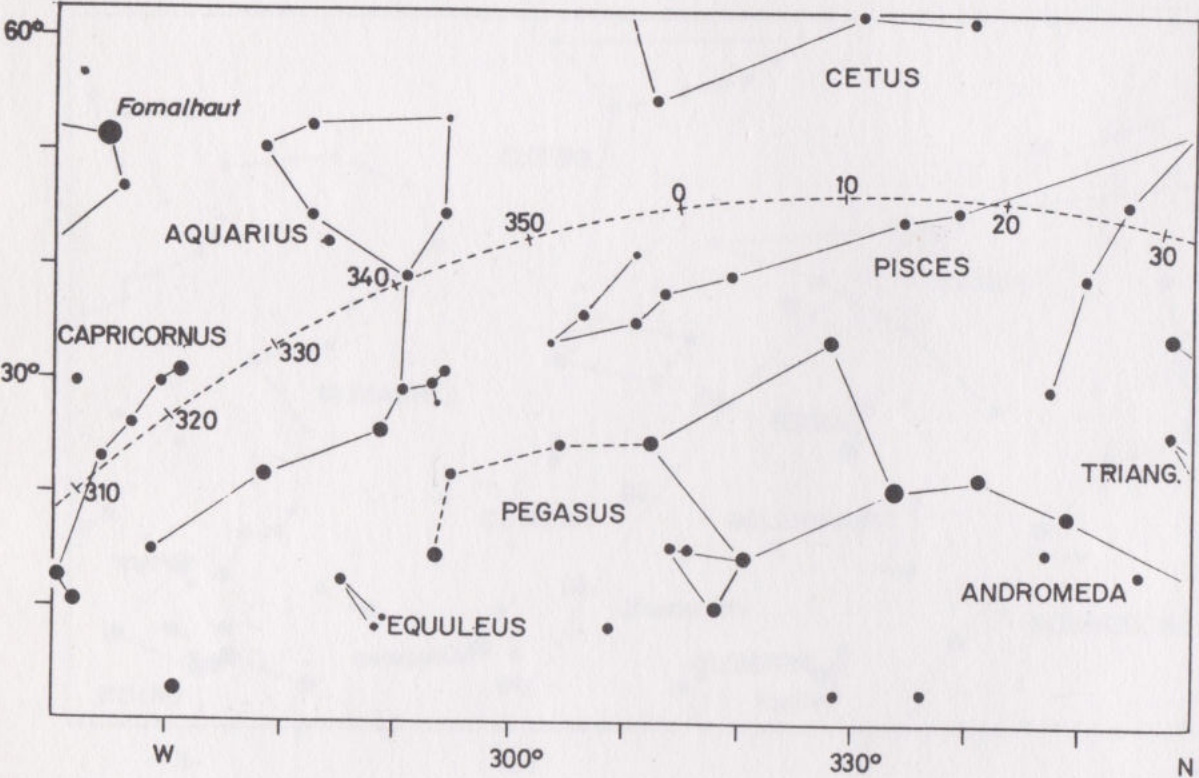
10R



11L

August 6 at 5^h
September 6 at 3^h
October 6 at 1^h
November 6 at 23^h
December 6 at 21^h

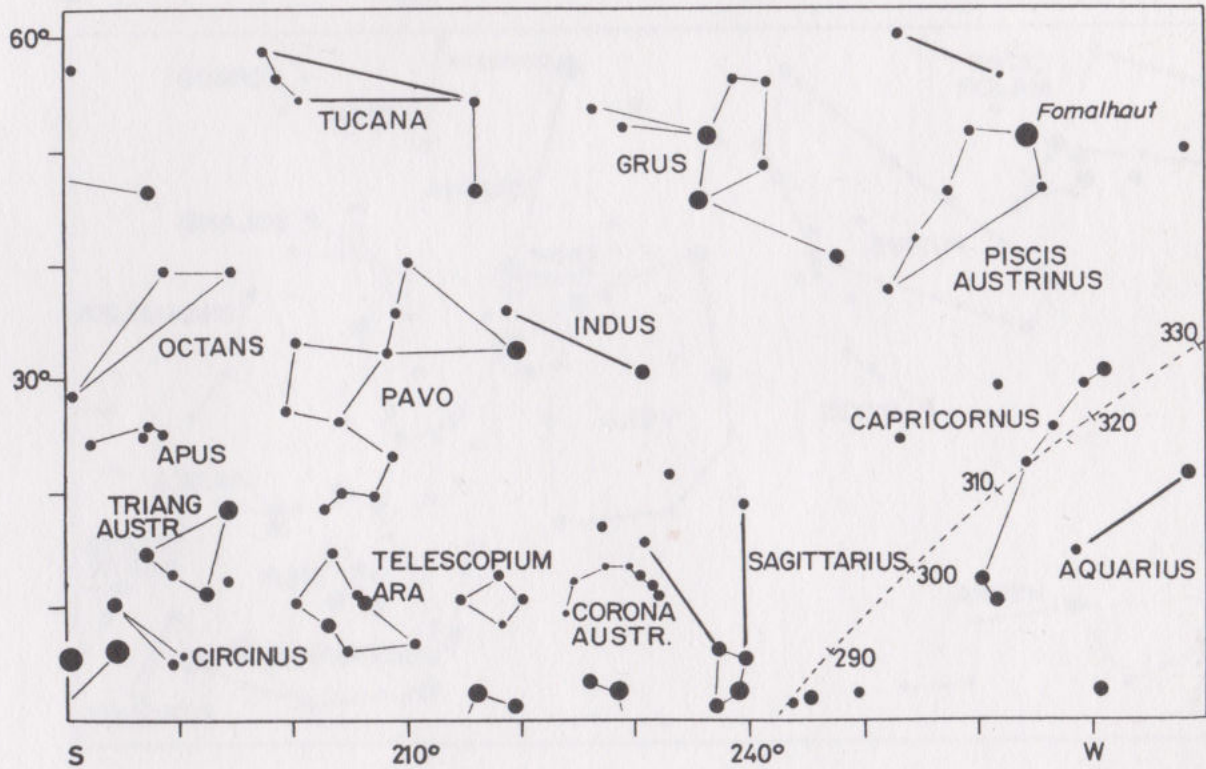
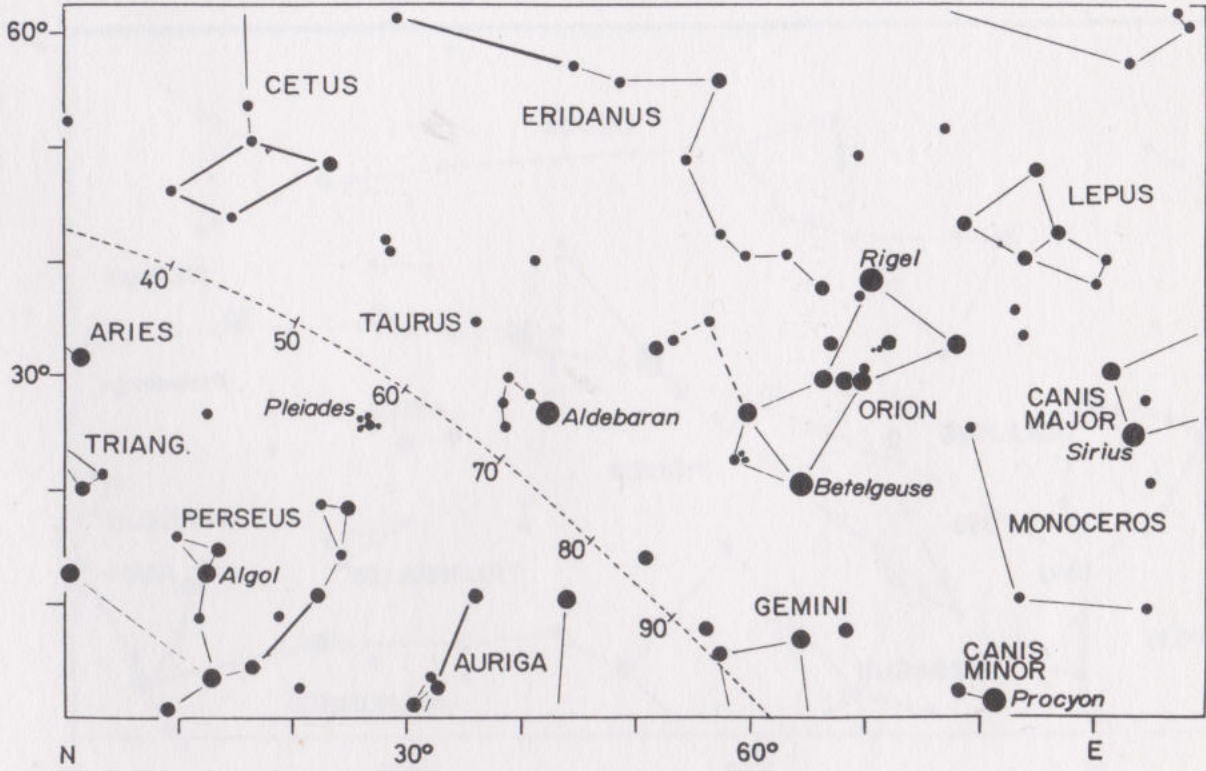
August 21 at 4^h
September 21 at 2^h
October 21 at midnight
November 21 at 22^h
December 21 at 20^h



August 6 at 5^h
 September 6 at 3^h
 October 6 at 1^h
 November 6 at 23^h
 December 6 at 21^h

August 21 at 4^h
 September 21 at 2^h
 October 21 at midnight
 November 21 at 22^h
 December 21 at 20^h

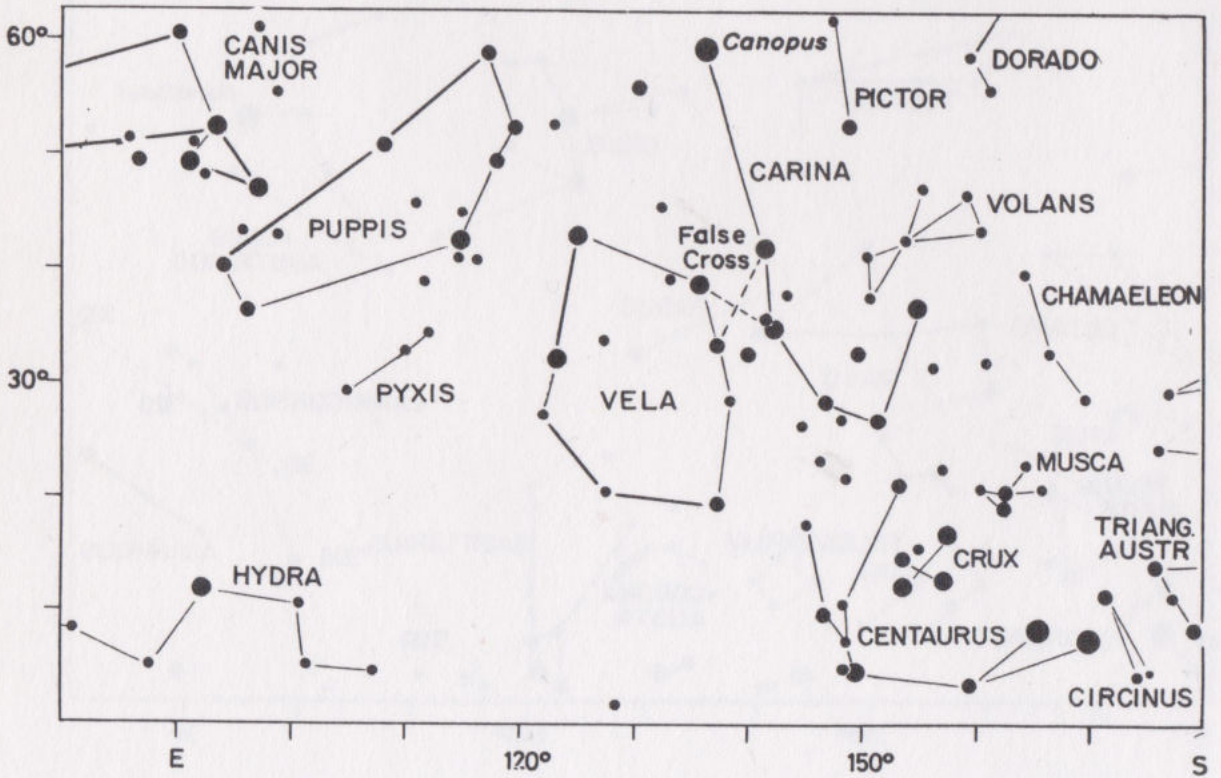
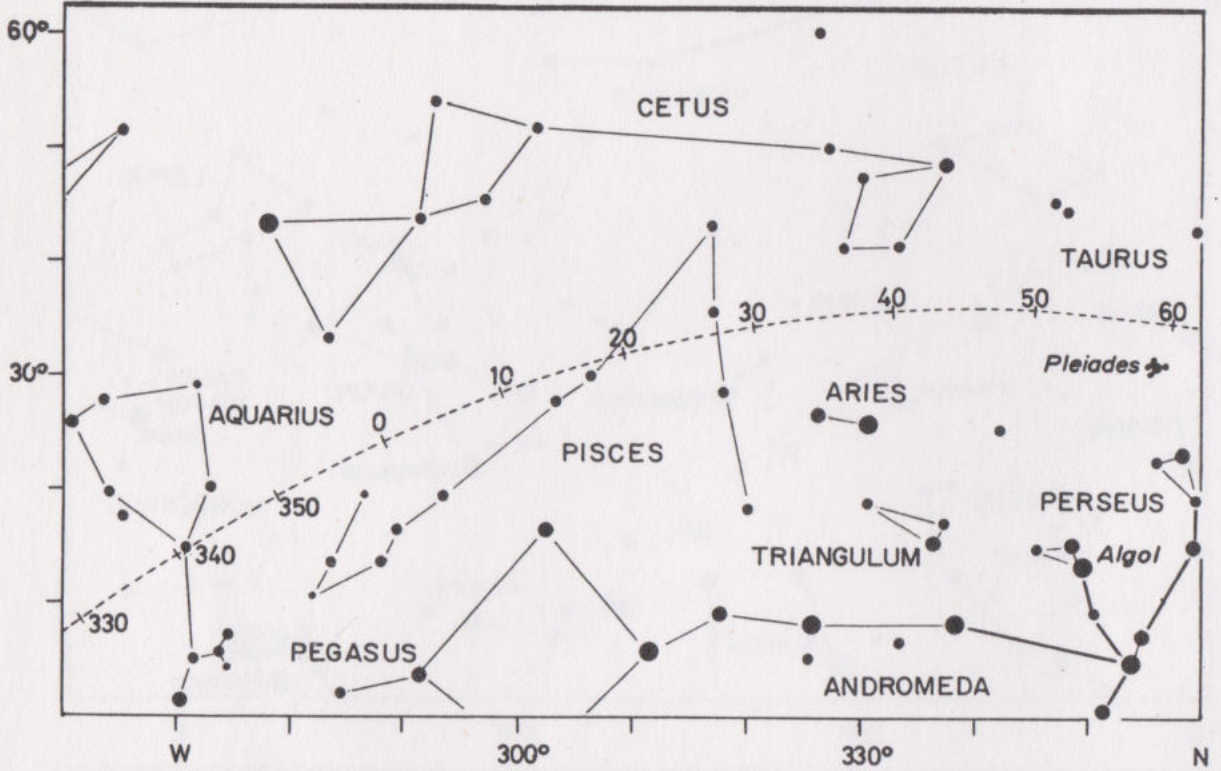
11R



12L

September 6 at 5^h
October 6 at 3^h
November 6 at 1^h
December 6 at 23^h
January 6 at 21^h

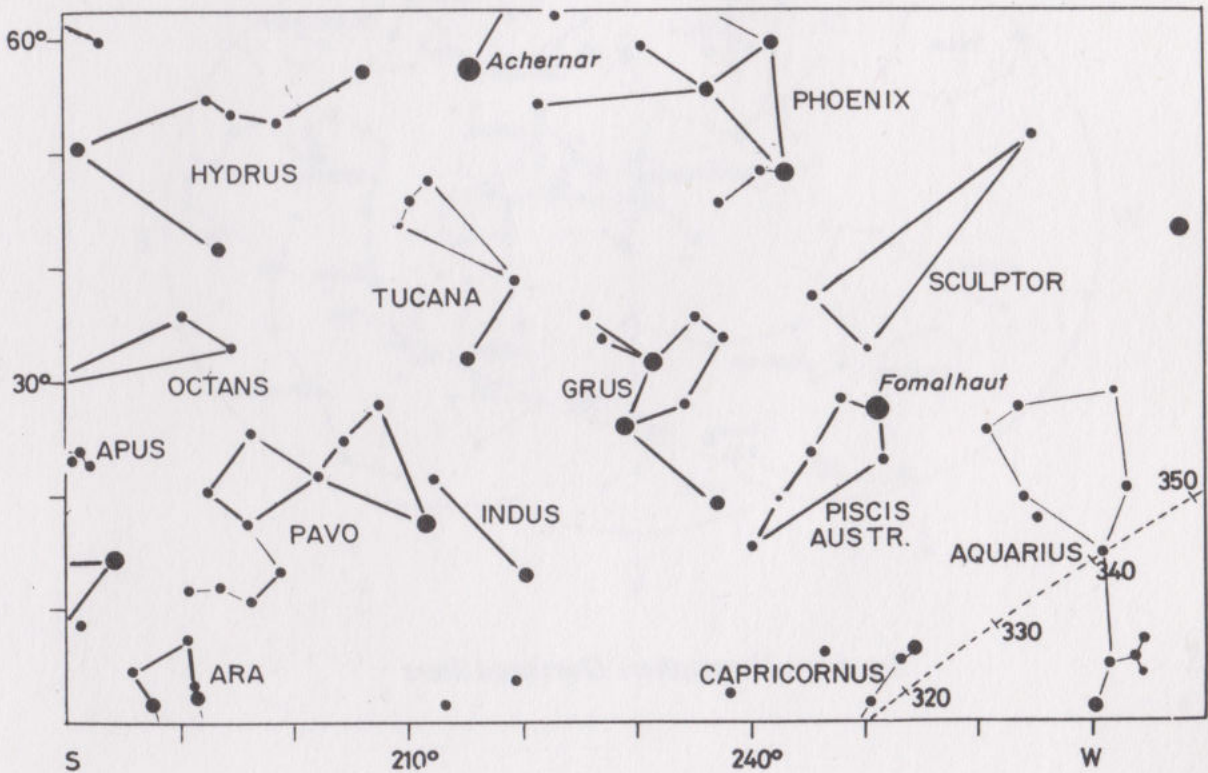
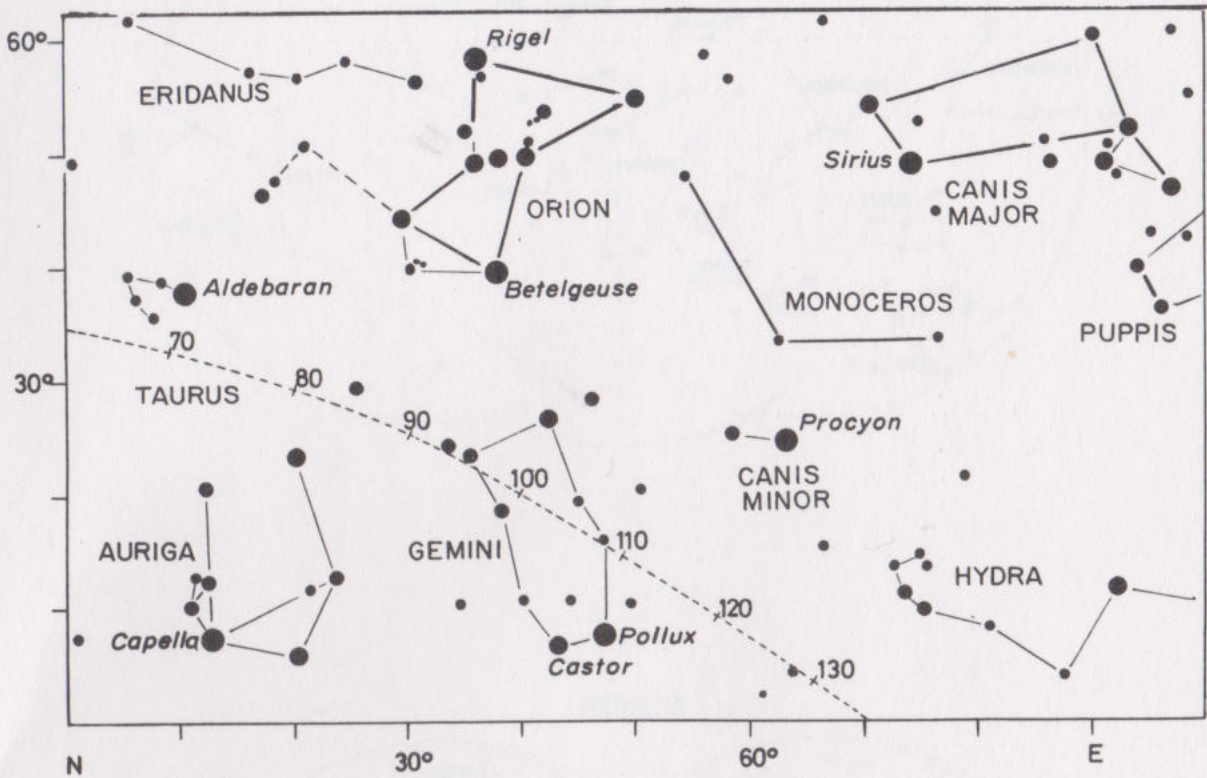
September 21 at 4^h
October 21 at 2^h
November 21 at midnight
December 21 at 22^h
January 21 at 20^h

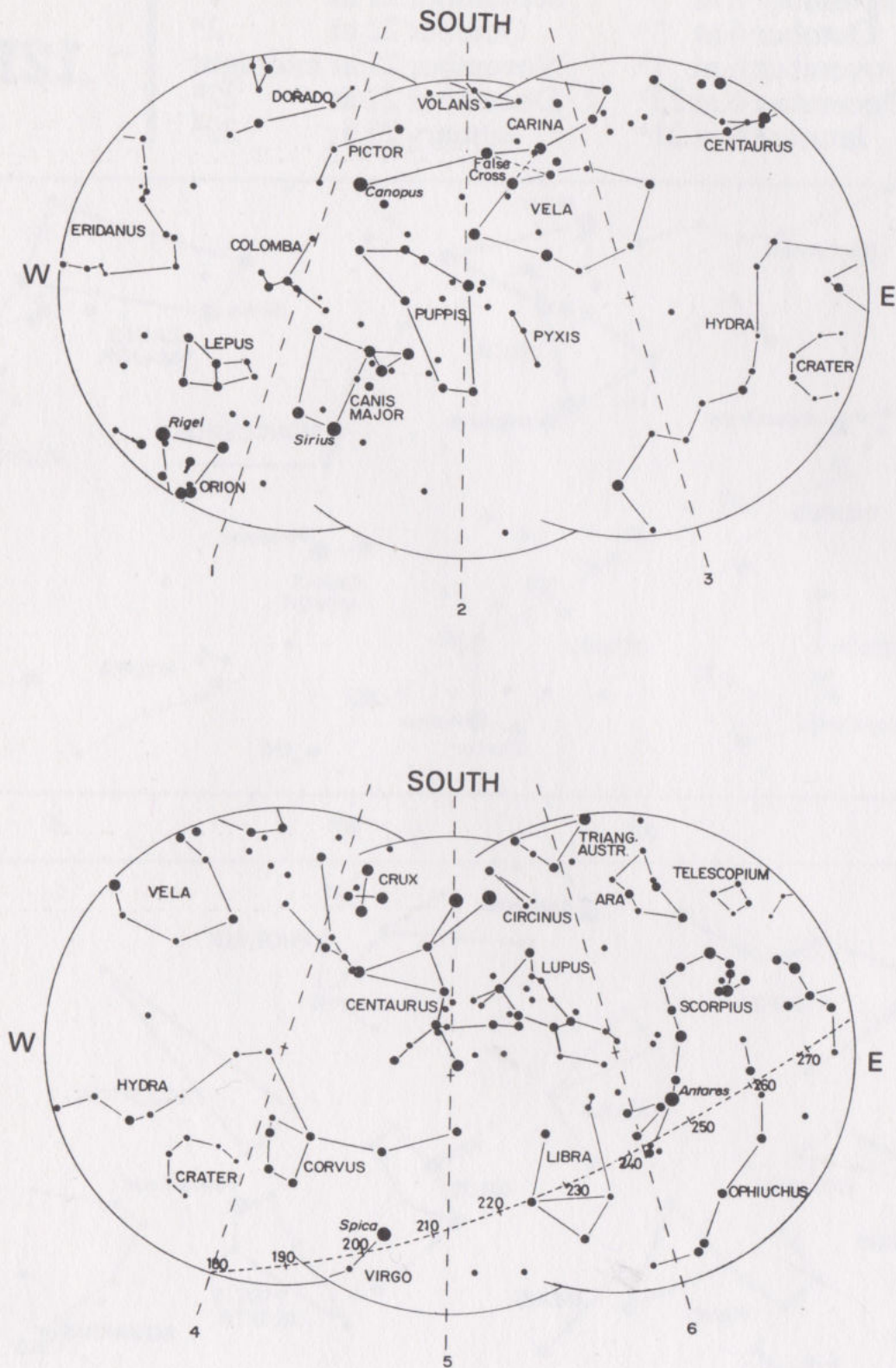


September 6 at 5^h
 October 6 at 3^h
 November 6 at 1^h
 December 6 at 23^h
 January 6 at 21^h

September 21 at 4^h
 October 21 at 2^h
 November 21 at midnight
 December 21 at 22^h
 January 21 at 20^h

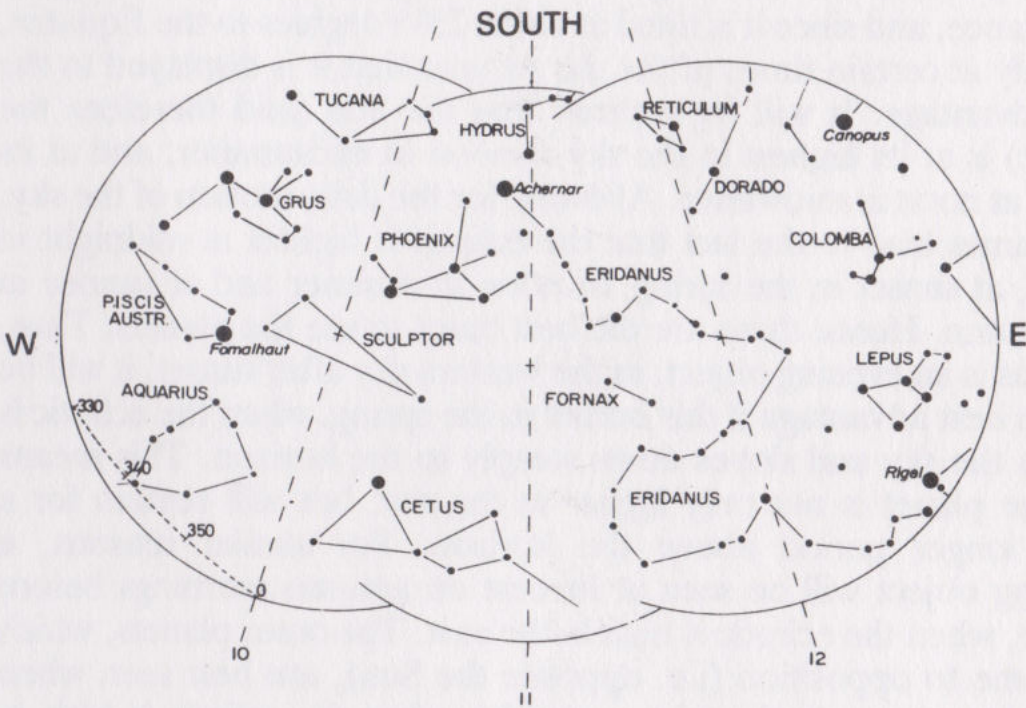
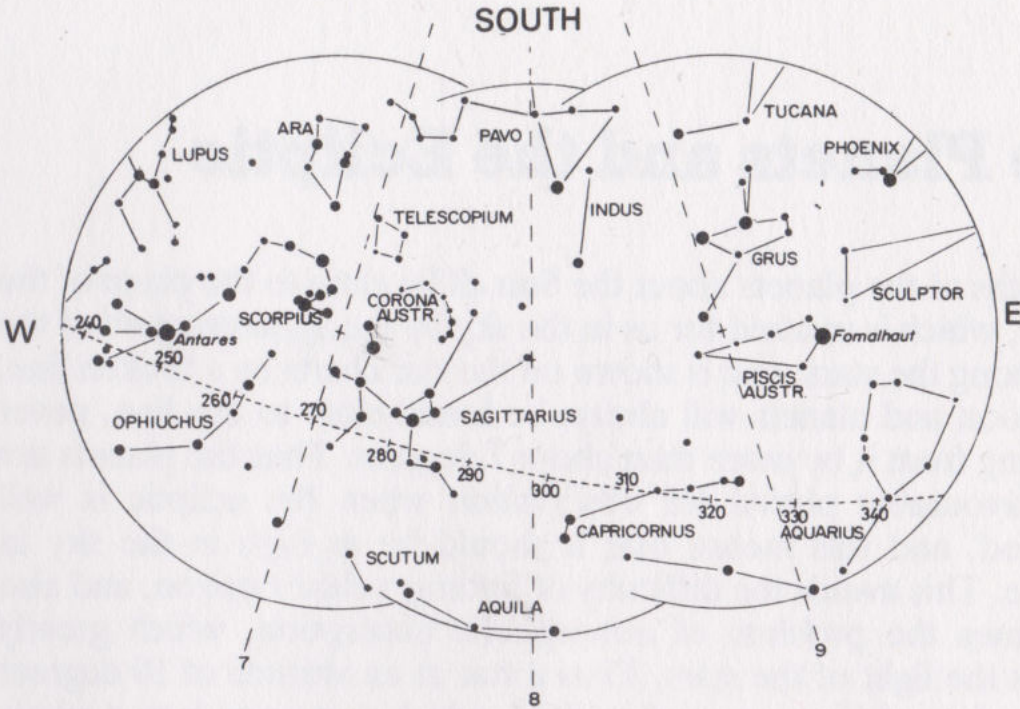
12R





Southern Hemisphere Overhead Stars

SOUTHERN STAR CHARTS



Southern Hemisphere Overhead Stars

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about $23\frac{1}{2}$ degrees to the Equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening object, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the horizon. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning object will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition (i.e. opposite the Sun), are best seen when opposition occurs in the winter months, when the ecliptic is high in the sky at midnight.

The seasons are reversed in the Southern Hemisphere, spring beginning at the September Equinox, when the Sun crosses the Equator on its way south, summer beginning at the December

Solstice, when the Sun is highest in the southern sky, and so on. Thus, the times when the ecliptic is highest in the sky, and therefore best placed for observing the planets, may be summarized as follows:

	<i>Midnight</i>	<i>Sunrise</i>	<i>Noon</i>	<i>Sunset</i>
Northern lats.	December	September	June	March
Southern lats.	June	March	December	September

In addition to the daily rotation of the celestial sphere from east to west, the planets have a motion of their own among the stars. The apparent movement is generally *direct*, i.e. to the east, in the direction of increasing longitude, but for a certain period (which depends on the distance of the planet) this apparent motion is reversed. With the outer planets this *retrograde* motion occurs about the time of opposition. Owing to the different inclination of the orbits of these planets, the actual effect is to cause the apparent path to form a loop, or sometimes an S-shaped curve. The same effect is present in the motion of the inferior planets, Mercury and Venus, but it is not so obvious, since it always occurs at the time of inferior conjunction.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are seen as evening objects in the western sky after sunset (at eastern elongations) or as morning objects in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus, if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		<i>Mercury</i>	<i>Venus</i>
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about 36 days before or after inferior conjunction. This will be about a month *after* greatest eastern elongation (as an evening object), or a month *before* greatest western elongation (as a morning object). No such rule can be given for Mercury, because its distance from the Earth and the Sun can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available. It is seldom seen as much as 10 degrees above the horizon in the twilight sky in northern latitudes, but this figure is often exceeded in the Southern Hemisphere. This favourable condition arises because the maximum elongation of 28 degrees can occur only when the planet is at aphelion (farthest from the Sun), and this point lies well south of the Equator. Northern observers must be content with smaller elongations, which may be as little as 18 degrees at perihelion. In general, it may be said that the most favourable times for seeing Mercury as an evening object will be in spring, some days before greatest eastern elongation; in autumn, it may be seen as a morning object some days after greatest western elongation.

Venus is the brightest of the planets and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening object, and it will be highest in the sky when it is a morning object in autumn, or an evening object in spring. The phenomena of Venus given in the table above can occur only in the months of January, April, June, August and November, and it will be realized that they do not all lead to favourable apparitions of the planet. In fact, Venus is to be seen at its best as an evening object in northern latitudes when eastern elongations occurs in June. The planet is then well north of the Sun in the preceding spring months, and is a brilliant object in the evening sky over a long period. In the Southern Hemisphere a November elongation is best. For similar reasons, Venus gives a prolonged display as a morning object in the months following western elongation in November (in northern latitudes) or in June (in the Southern Hemisphere).

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning objects after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be nearest to the Earth (and therefore at their brightest), and will then be on the meridian at midnight, due south in northern latitudes, but due north in the Southern Hemisphere. After opposition they are evening objects, setting earlier each

evening until they set in the west with the Sun at the next conjunction. The change in brightness about the time of opposition is most noticeable in the case of Mars, whose distance from Earth can vary considerably and rapidly. The other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of some importance, for at a December opposition in northern latitudes the planets will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so makes a less impressive appearance. In the Southern Hemisphere, the reverse conditions apply; a June opposition being the best, with the planet in Sagittarius at an altitude which can reach 80 degrees above the northern horizon for observers in South Africa.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August. It may then be brighter even than Jupiter, but rather low in the sky in Aquarius for northern observers, though very well placed for those in southern latitudes. These favourable oppositions occur every fifteen or seventeen years (1956, 1971, 1988, 2003) but in the Northern Hemisphere the planet is probably better seen at an opposition in the autumn or winter months, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspects of its rings, as well as on the distance from Earth and Sun. The rings were inclined towards the Earth and Sun in 1980 and are currently near their maximum opening. The next passage of both Earth and Sun through the ring-plane will not occur until 1995.

Uranus, *Neptune*, and *Pluto* are hardly likely to attract the attention of observers without adequate instruments.

Phases of the Moon

1989

<i>New Moon</i>			<i>First Quarter</i>			<i>Full Moon</i>			<i>Last Quarter</i>		
	d	h m		d	h m		d	h m		d	h m
Jan.	7	19 22	Jan.	14	13 58	Jan.	21	21 33	Jan.	30	02 02
Feb.	6	07 37	Feb.	12	23 15	Feb.	20	15 32	Feb.	28	20 08
Mar.	7	18 19	Mar.	14	10 11	Mar.	22	09 58	Mar.	30	10 21
Apr.	6	03 33	Apr.	12	23 13	Apr.	21	03 13	Apr.	28	20 46
May	5	11 46	May	12	14 19	May	20	18 16	May	28	04 01
June	3	19 53	June	11	06 59	June	19	06 57	June	26	09 09
July	3	04 59	July	11	00 19	July	18	17 42	July	25	13 31
Aug.	1	16 06	Aug.	9	17 28	Aug.	17	03 07	Aug.	23	18 40
Aug.	31	05 44	Sept.	8	09 49	Sept.	15	11 51	Sept.	22	02 10
Sept.	29	21 47	Oct.	8	00 52	Oct.	14	20 32	Oct.	21	13 19
Oct.	29	15 27	Nov.	6	14 11	Nov.	13	05 51	Nov.	20	04 44
Nov.	28	09 41	Dec.	6	01 26	Dec.	12	16 30	Dec.	19	23 54
Dec.	28	03 20									

All times are G.M.T.
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Longitudes of the Sun, Moon and Planets in 1988

DATE		<i>Sun</i> °	<i>Moon</i> °	<i>Venus</i> °	<i>Mars</i> °	<i>Jupiter</i> °	<i>Saturn</i> °
January	6	286	262	264	23	56	276
	21	301	110	283	31	56	278
February	6	317	313	303	40	57	280
	21	332	156	322	49	58	281
March	6	345	321	338	57	59	282
	21	0	165	357	66	62	283
April	6	16	14	16	76	64	284
	21	31	209	35	85	67	284
May	6	45	53	54	94	71	284
	21	60	243	72	103	74	283
June	6	75	104	92	113	78	282
	21	90	291	110	123	81	281
July	6	104	138	128	132	85	280
	21	118	328	146	141	88	279
August	6	134	183	166	152	91	278
	21	148	21	183	161	94	278
September	6	163	227	202	171	97	277
	21	178	74	220	181	99	277
October	6	192	259	237	191	100	278
	21	208	111	254	201	101	279
November	6	224	306	271	211	101	280
	21	239	158	285	221	100	281
December	6	254	343	297	232	99	283
	21	269	190	305	242	97	284

Longitude of *Uranus* 273°
Neptune 281°

Moon: Longitude of ascending node
 Jan. 1: 338° Dec. 31: 319°

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The

monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the previous page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples

In the southern hemisphere two planets are seen in the north-western sky one evening early in February. Identify them.

The southern star chart 1L shows the sky from W→N in early February and shows longitudes $0^\circ - 90^\circ$. Reference to the table on p.71 gives for February 6, the longitude of Mars as 40° and Jupiter 57° . No other planets are in this area.

The positions of the Sun and Moon can be plotted on the star maps in the same manner as for the planets. The average daily motion of the Sun is 1° , and of the Moon 13° . For the Moon an indication of its position relative to the ecliptic may be obtained from a consideration of its longitude relative to that of the ascending node. The latter changes only slowly during the year as will be seen from the values given on the preceding page. Let us call the difference in longitude of Moon-node, d . Then if $d=0^\circ$, 180° or 360° the Moon is on the ecliptic. If $d=90^\circ$ the Moon is 5° north of the ecliptic and if $d=270^\circ$ the Moon is 5° south of the ecliptic.

On September 6 the Moon's longitude is given as 227° and the longitude of the node is found by interpolation to be about 325° . Thus $d=262^\circ$ and the Moon is about 5° south of the ecliptic. Its position may be plotted on northern star charts 4L, 5L, 6R and 7R: and southern star charts 3L, 3R, 4R, 7L, and 8L.

Some Events in 1989

ECLIPSES

There will be four eclipses, two of the Sun and two of the Moon.

February 20: total eclipse of the Moon – N. America, Australasia, Asia, E. Africa, N. E. Europe.

March 7: partial eclipse of the Sun – Hawaii, N. America, Greenland, Asia.

August 17: total eclipse of the Moon – Asia, Europe, Africa, the Americas.

August 31: partial eclipse of the Sun – S. E. Africa.

THE PLANETS

Mercury may be seen more easily from northern latitudes in the evenings about the time of greatest eastern elongation (May 1) and in the mornings around greatest western elongation (October 10). In the Southern Hemisphere the corresponding dates are February 18 (morning) and August 29 (evening).

Venus is visible in the mornings until March, and in the evenings from May to December.

Mars is visible in the evenings until July and in the mornings from November onwards.

Jupiter is at opposition on December 27.

Saturn is at opposition on July 2.

Uranus is at opposition on June 24.

Neptune is at opposition on July 2.

Pluto is at opposition on May 4.

JANUARY

New Moon: January 7

Full Moon: January 21

EARTH is at perihelion (nearest to the Sun) on January 1 at a distance of 147 million kilometres.

MERCURY attains its greatest eastern elongation (19°) from the Sun on January 9. It is visible as an evening object for the first three weeks of the month though for observers in the latitudes of the British Isles the period of visibility is reduced to two weeks, starting on about January 3. This elusive planet may be glimpsed low above the south-western horizon at the end of evening civil twilight.

VENUS, magnitude -3.9 , is a brilliant object in the morning sky though for observers in the latitudes of the British Isles it is unlikely to be seen during the last week of the month because of its low altitude as it moves closer to the Sun.

MARS is visible as an evening object in the western sky, its magnitude fading during the month from -0.1 to $+0.5$. Figure 1 shows the path of Mars amongst the stars during the first few months of the year.

JUPITER, magnitude -2.6 , is a brilliant evening object in Taurus. Figure 1 shows the path of Jupiter amongst the stars throughout 1989. It will be seen from this that Jupiter is almost stationary south of the Pleiades and west of the Hyades in January.

SATURN, for observers in northern temperate latitudes, remains too close to the Sun for observation throughout January. Further south, observers may hope to detect the planet towards the end of the month, as a morning object low in the east for a short while before the growing twilight renders observation impossible.

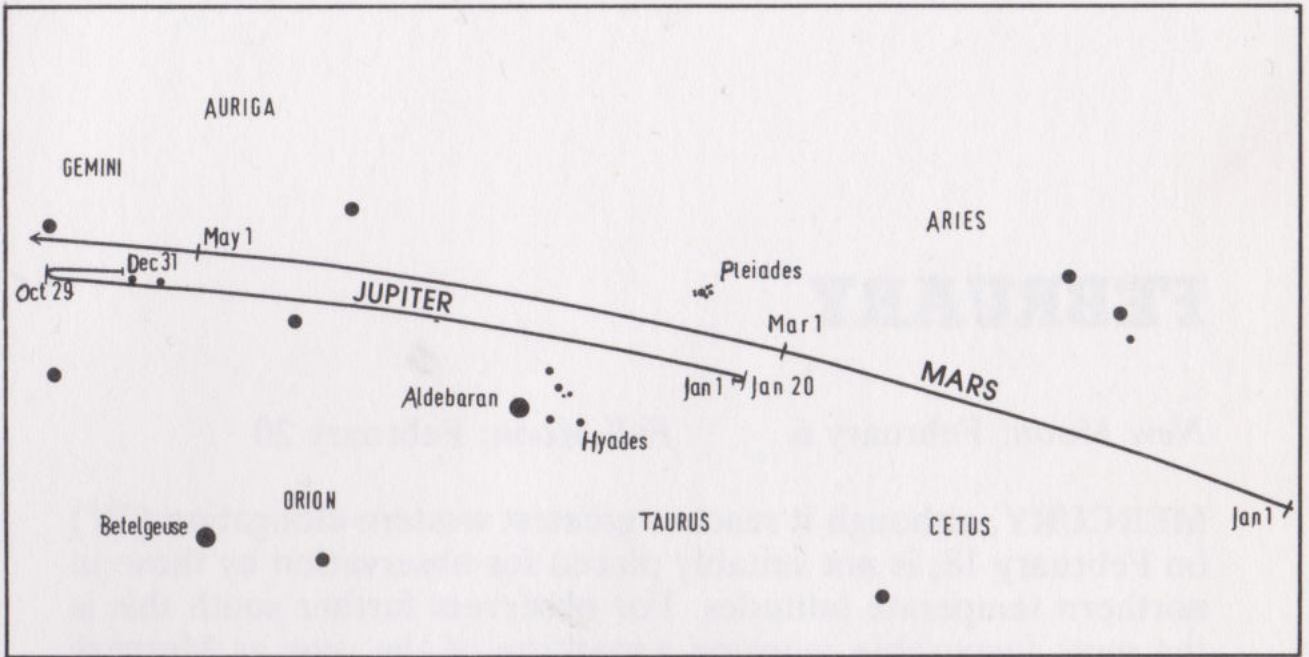


Figure 1. The paths of Mars and Jupiter.

THE QUADRANTIDS. In many ways the Quadrantid meteor shower, which reaches a short, sharp maximum very early each January (January 3 or 4) is unique. It can be spectacular, and at times has been known to produce over 100 meteors per hour, but the peak of the display is so brief that an inconvenient moon or cloudy spell can hide it completely.

The Quadrantid shower seems to be fairly young, with a high percentage of small meteoroids concentrated in a stream with a cross-sectional diameter of no more than a million and a quarter miles. The stream has its ascending node close to the orbit of Jupiter, and there are considerable perturbations, which makes it difficult to predict just where the stream will be in relation to the Earth when the display should be at its best. Apparently the perihelion distance has shown a steady increase over the centuries, and is now just inside the mean distance between the Earth and the Sun. If it continues to increase, it will no longer intersect the Earth's orbit, and in no more than 500 years from now we may have lost the shower permanently.

The radiant is at RA $15^{\text{h}} 28^{\text{m}}$, dec. $+50^{\circ}$ – close to the star Beta Boötis, the area once marked by the now-rejected constellation of Quadrans Muralis (the Mural Quadrant). In 1989 the Moon will not be obtrusive at the maximum of the shower, so that with luck we may hope for at least a reasonable display of Quadrantids.

FEBRUARY

New Moon: February 6

Full Moon: February 20

MERCURY, although it reaches greatest western elongation (26°) on February 18, is not suitably placed for observation by those in northern temperate latitudes. For observers further south this is the most favourable morning apparition of the year as Mercury may be seen from the beginning of February until the middle of March. Figure 2 shows, for observers in latitude $S.35^\circ$, the changes in azimuth (true bearing from north through east, south and west) and altitude of Mercury on successive mornings when the Sun is 6° below the horizon. This condition is known as the beginning of morning civil twilight, and in this latitude and at this time of year occurs about 30 minutes before sunrise. The changes in the brightness of the planet are indicated by the relative sizes of the circles marking Mercury's positions at five-day intervals. It will be noticed that Mercury is brightest after it reaches greatest western elongation. At the beginning of the month inexperienced observers may be misled by the appearance of Venus in the same part of the sky. Venus is 5 magnitudes brighter than Mercury.

VENUS is moving towards the Sun, though observers in tropical and southern latitudes will still be able to see it for a short while in the eastern morning sky before dawn, for the first three weeks of the month.

MARS, magnitude $+0.8$, continues to be visible as an evening object in the western sky until around midnight.

JUPITER, magnitude -2.4 , continues to be visible as a conspicuous evening object in Taurus.

SATURN is emerging from the morning twilight to be visible for a

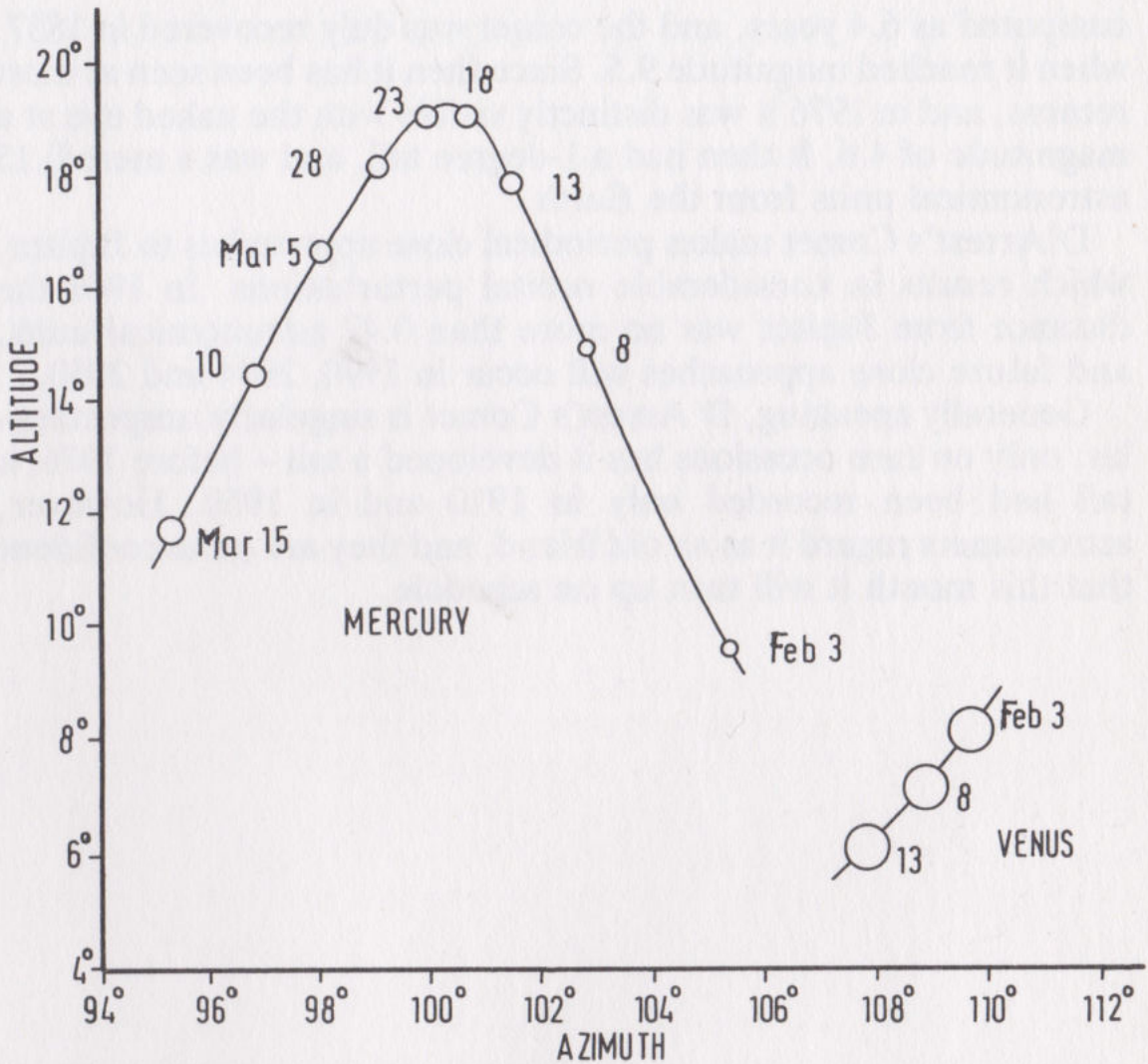


Figure 2. Morning apparition of Mercury for latitude S.35°.

short while low in the east. It will still be a difficult object for observers in the latitudes of the British Isles early in the month, those with telescopes should also refer to the notes for July.

D'ARREST'S COMET. On February 4 D'Arrest's periodical comet comes to perihelion. At times it can just attain naked-eye visibility. It will not do so this year – the maximum magnitude is only 6.4 – but at least it is one of the best-known and most 'reliable' of the periodical comets.

It was discovered on June 28, 1851 by Heinrich d'Arrest, of Leipzig – an astronomer best remembered, perhaps, for being co-discoverer with Galle of the planet Neptune, on the basis of Le Verrier's calculations (1846). When he found the comet, it was of magnitude 10, and never became much brighter. The period was

computed as 6.4 years, and the comet was duly recovered in 1857, when it reached magnitude 9.5. Since then it has been seen at most returns, and in 1976 it was distinctly visible with the naked eye at a magnitude of 4.6. It then had a 1-degree tail, and was a mere 0.15 astronomical units from the Earth.

D'Arrest's Comet makes periodical close approaches to Jupiter, which results in considerable orbital perturbations. In 1968 the distance from Jupiter was no more than 0.42 astronomical units, and future close approaches will occur in 1990, 2034 and 2050.

Generally speaking, D'Arrest's Comet is singularly unspectacular; only on rare occasions has it developed a tail – before 1976, a tail had been recorded only in 1910 and in 1950. However, astronomers regard it as an old friend, and they are quite confident that this month it will turn up on schedule.

MARCH

New Moon: March 7

Full Moon: March 22

Summer Time in Great Britain and Northern Ireland commences on March 26.

Equinox: March 20

MERCURY, magnitude -0.2 , may be seen by those in equatorial and southern latitudes, as a morning object for the first half of the month. See Figure 2 given with the notes for February.

VENUS remains too close to the Sun throughout the month for observation to be possible.

MARS, magnitude $+1.2$, is still visible as an evening object in the western sky. The planet is well known for its slight reddish tint and this is a useful aid to its identification. Note that as Mars is in Taurus there are two reddish stars in the same part of the sky, Aldebaran in Taurus and Betelgeux in Orion. Mars passes between the Hyades and the Pleiades and, on March 12, passes 2° N. of Jupiter (see Figure 1).

JUPITER continues to be visible as a brilliant object in the western sky in the evenings.

SATURN, magnitude $+0.6$, is a morning object in Sagittarius. Figure 3 shows the path of the planet amongst the stars throughout the year. Saturn is about one-third of a magnitude brighter than Antares, in Scorpio.

PLANETARY CONJUNCTIONS. On March 12 the conjunction of Mars and Jupiter will be interesting to observe (and photograph?), even

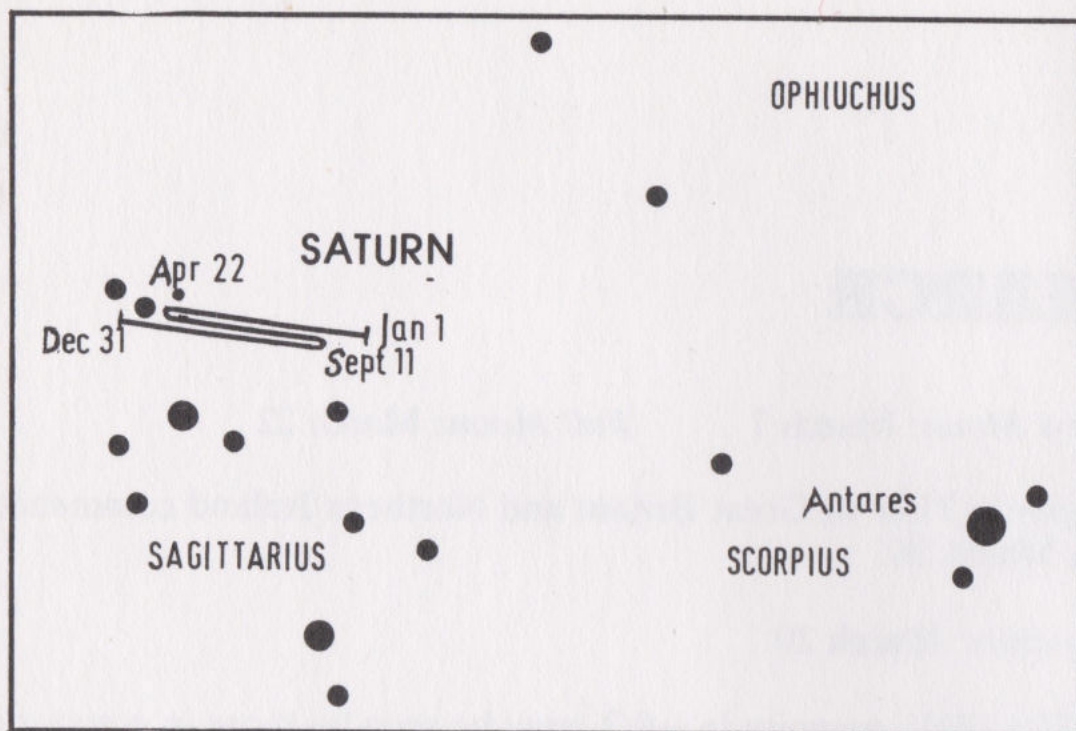


Figure 3. The path of Saturn.

though Mars is now below the first magnitude. Mutual planetary occultations are very rare, but reasonably close conjunctions are not. During the next few years, for example, we have the following cases, all within 3 degrees apart from those marked *, which are slightly greater:

Mercury/Venus 1989 Apr. 4, May 16: 1990 Feb. 4*, Sept. 14*, Oct. 16, Dec. 18: 1991 Aug. 7, 20*, 29*.

Mercury/Mars 1989 Aug. 5, Sept. 22*, Oct. 27: 1991 Oct. 14, Dec. 13: 1992 Jan. 10.

Mercury/Jupiter 1989 July 2: 1990 July 7: 1991 July 15, Aug. 22, Sept. 10.

Mercury/Saturn 1989 Dec. 16: 1990 Jan. 10, Feb. 3: 1991 Feb. 5.

Venus/Mars 1989 July 12: 1991 June 23, July 22*: 1992 Feb. 19.

Venus/Jupiter 1989 May 23: 1990 Aug. 12: 1991 June 17, Aug. 23*, Oct. 17.

Venus/Saturn 1989 Nov. 15*: 1990 Feb. 7*, 14*: 1991 Jan. 1.

Mars/Jupiter 1991 June 14: 1993 Sept. 7.

Mars/Saturn 1990 Feb. 28: 1992 Mar. 6.

Jupiter and Saturn will not be in conjunction until the year 2000 May 31. Of course these conjunctions are not important, and – contrary to some curious Press statements – can have no effect upon the Earth or anything else.

APRIL

New Moon: April 6

Full Moon: April 21

MERCURY is too close to the Sun for observation at first. During the second half of the month it is visible as an evening object, magnitude -1.3 to $+0.4$. For observers in northern temperate latitudes this will be the most favourable evening apparition of the year. Figure 4 shows, for observers in latitude $N.52^\circ$, the changes in azimuth (true bearing from the north through east, south and west) and altitude of Mercury on successive evenings when the Sun is 6° below the horizon. This condition is known as the end of evening civil twilight and in this latitude and at this time of year occurs about 40 minutes after sunset. The changes in the brightness of the planet are indicated by the relative sizes of the circles marking Mercury's positions at five-day intervals. It will be noticed that Mercury is brightest before it reaches greatest eastern elongation on May 1. Its magnitude on April 14 is -1.4 , while by May 4 it is only $+0.7$.

VENUS passes slowly through superior conjunction on April 4 and therefore remains unsuitably placed for observation throughout the month.

MARS continues to be visible as an evening object in the western sky, passing from Taurus into Gemini at the end of April.

JUPITER, magnitude -2.0 , is still visible as a brilliant object in the western sky in the evenings.

SATURN continues to be visible as a morning object, magnitude $+0.5$. By the end of the month observers in the latitudes of the British Isles will notice that it is due south at sunrise.

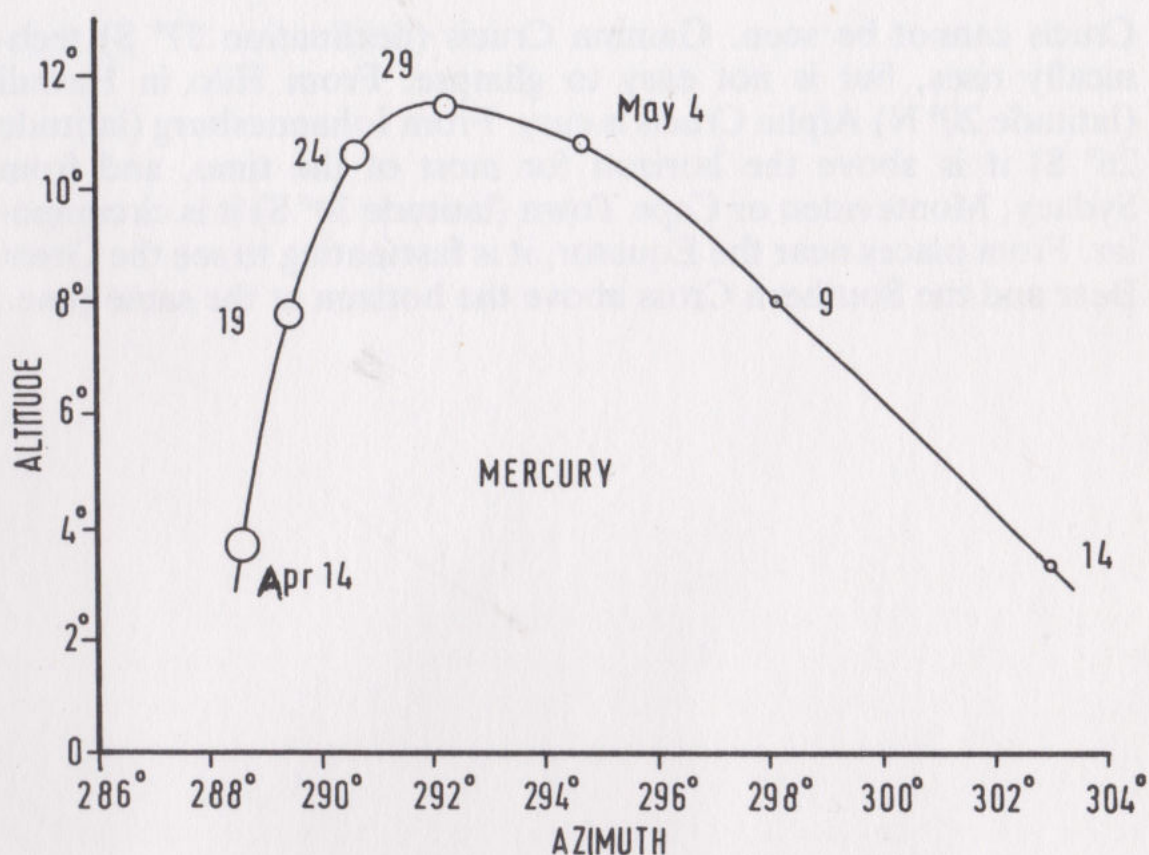


Figure 4. Evening apparition of Mercury for latitude N.52°.

WHERE CAN YOU SEE THE SOUTHERN CROSS? Of all the constellations, the two most famous are probably Ursa Major (the Great Bear) in the northern hemisphere, and Crux Australis (the Southern Cross) in the southern. During April, Crux is excellently placed for observation from countries such as Australia and South Africa, but in Europe it cannot be seen at all, and there are many people who believe that in order to observe it you must travel south of the equator.

This is not so. The declination of Acrux or Alpha Crucis, the brightest star in the Cross, is -63 degrees. The result is that in theory it rises from any latitude south of 27 degrees north, while from anywhere south of 27 degrees south it is circumpolar – i.e. it never sets. Of course, the effects of refraction complicate this slightly, and in any case it is never easy to see a star which is only a degree or two above the horizon, but the principles are straightforward enough.

For example, La Palma, in the Canary Islands (where the new observatory has been set up) is at latitude 28° N, so that Alpha

Crucis cannot be seen. Gamma Crucis (declination 57° S) technically rises, but is not easy to glimpse. From Hilo in Hawaii (latitude 20° N) Alpha Crucis is easy. From Johannesburg (latitude 26° S) it is above the horizon for most of the time, and from Sydney, Montevideo or Cape Town (latitude 34° S) it is circumpolar. From places near the Equator, it is fascinating to see the Great Bear and the Southern Cross above the horizon at the same time.

MAY

New Moon: May 5

Full Moon: May 20

MERCURY is at greatest eastern elongation (21°) on the first day of the month and therefore continues to be visible as an evening object for the first two weeks of the month, its magnitude fading during that period from $+0.4$ to $+3$. Observers should refer to Figure 4, given with the notes for April.

VENUS, magnitude -3.9 , may be seen as a brilliant object in the evening sky after the first few days of the month. It appears low above the western horizon for a short while after sunset. Venus passes just north of Jupiter on May 23.

MARS is still visible in the western sky in the evenings but is no longer a conspicuous object as its magnitude has faded to $+1.7$. By the end of the month it is only 40° from the Sun. Its path amongst the stars is shown in Figure 5, given with the notes for June.

JUPITER, magnitude -2.0 , is moving noticeably closer to the Sun and only visible for a short while in the evening sky. By the middle of the month it will be lost in the long evening twilight, for observers in northern temperate latitudes. Observers further south may hope for no more than another week or ten days of visibility.

SATURN, magnitude $+0.3$, is still visible as a morning object and is now rising before midnight.

GAMMA VIRGINIS. One of the most famous binaries in the sky is well on view this month: Gamma Virginis, sometimes still known by one of its old proper names – Arich, Porrima or Postvarta. Its R.A. is $12^h 42^m$, and since its declination is $-1^\circ 27'$ it is visible from all inhabited countries. It makes up part of the Y-pattern of Virgo,

and with the naked eye it looks like an ordinary star of magnitude 2.7. In fact there are two virtually identical components, each of magnitude 3.5 and of spectral type FO. The distance from us is 36 light-years.

The double nature of Gamma Virginis was discovered in 1718 by Bradley and Pound; Cassini also saw it in 1720. In 1833 Sir John Herschel calculated the orbit, and predicted that by 1836 the separation would be only $0''.3$, so that the star would appear single in most telescopes. The period is 171.4 years, and by 1920 the separation had reached its maximum of $6''.2$, making Gamma Virginis one of the most spectacular pairs in the sky. Since then it has been closing up again; the present separation is $3''.0$, but by the year 2000 it will be only $1''.8$, and by 2116 the star will again be separable only with very large telescopes. The orbital eccentricity is 0.88, and the actual separation ranges between 3 and 70 astronomical units. The total luminosity of the pair is about seven times that of the Sun. At the moment Gamma Virginis is still an easy pair for small telescopes – so look at it while you still can!

JUNE

New Moon: June 3

Full Moon: June 19

Solstice: June 21

MERCURY attains its greatest western elongation (23°) on June 18. For observers in the latitudes of the British Isles the long duration of twilight makes observation impossible, but nearer the Equator and in the more populous areas of the southern hemisphere Mercury can be seen as a morning object low above the eastern horizon at the time of beginning of morning civil twilight, throughout the month.

VENUS, magnitude -3.9 , is a brilliant object in the evening sky, though still only visible low in the west for a short while after sunset (in the latitudes of the British Isles this period is only about half-an-hour). Venus passes south of Castor and Pollux during the second half of the month.

MARS, magnitude $+1.8$, is still visible in the western sky in the early evenings though for observers in the latitudes of the British Isles it will have disappeared from view in the long evening twilight before the end of the month. Mars is in Gemini, passing south of Castor and Pollux early in June (see Figure 5).

JUPITER passes through conjunction on June 9 and for most observers it remains unobservable throughout the month. However observers in equatorial latitudes may be able to glimpse the planet rising in the east shortly before dawn, at the very end of the month.

SATURN, magnitude $+0.1$, is now visible for the greater part of the night. Saturn is in Sagittarius.

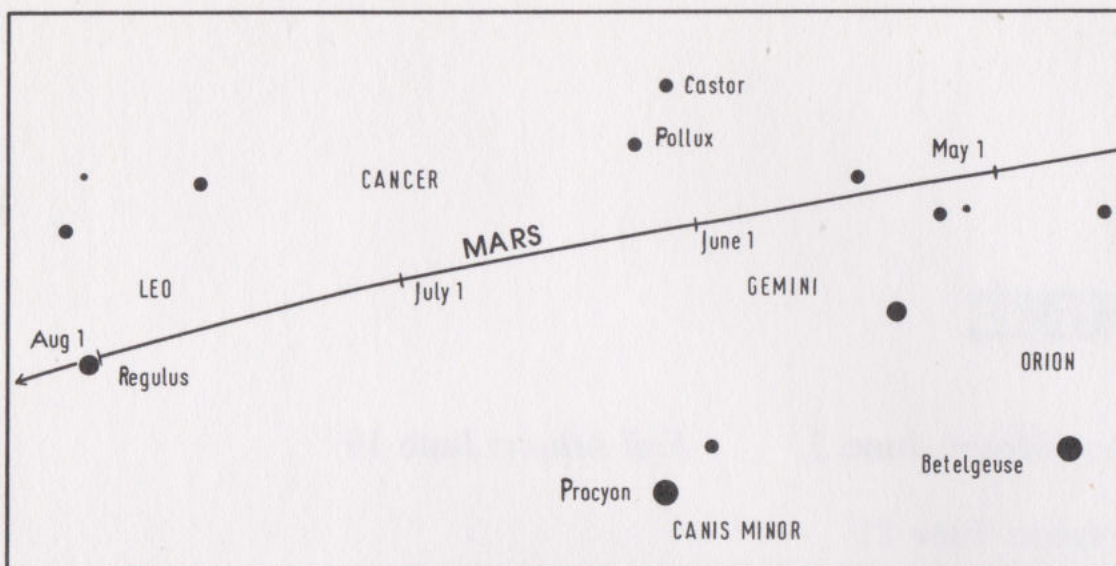


Figure 5. The path of Mars.

BETA LIBRÆ: THE GREEN STAR? Libra, the Scales or Balance, is one of the more obscure Zodiacal constellations. Originally it was known as Chelæ Scorpīi, the Scorpion's Claws, and it has even purloined the star Gamma Scorpīi, which is now known as Sigma Libræ. It is not difficult to identify, and is well placed in June; the four main stars (Alpha, Beta, Gamma and Sigma) make up a rough quadrangle. Some Greek legends associate it, rather loosely, with Mochis, the inventor of weights and measures. There are not many interesting objects, but Delta Libræ is one of the brighter Algol-type eclipsing binaries, ranging between magnitudes 4.8 and 6.1 in a period of 2.33 days.

All the leading stars have cumbersome proper names, which have (predictably) fallen into disuse. Beta Libræ, actually the brightest star in the constellation, is Zubenelchemale. It has a B8-type spectrum, an absolute magnitude of -0.2 , and is 121 light-years away. It is interesting because some observers have reported that it has a distinctly greenish tinge.

Green stars are, in general, confined to the fainter components of binaries where the primary is red – Antares and Alpha Herculis being the prime examples, where contrast plays an important role. But Beta Libræ is a single star, and if it were really green it would be, if not unique, at least very unusual. On the other hand, most observers will certainly call it white, or at the very most slightly bluish. It is worth looking at Beta Libræ, preferably with a reflector; it will be interesting to see whether anyone today classes it as greenish.

JULY

New Moon: July 3

Full Moon: July 18

EARTH is at aphelion (farthest from the Sun) on July 4 at a distance of 152 million kilometres.

MERCURY is visible as a morning object for the first week of the month and as an evening object for the last few days of the month, though not for observers in northern temperate latitudes where the continuing lengthy twilight makes observation impossible.

VENUS continues to be visible as a brilliant object in the western sky for a short while after sunset. On July 23 Venus passes $1^{\circ}.2$ N. of Regulus. Older readers may remember that it was thirty years ago (1959 July 7) when a spectacular event occurred as Venus occulted Regulus.

MARS, except for observers in northern temperate latitudes, is still visible low in the western sky in the early evenings. Its magnitude is +1.8 and it moves steadily from Cancer into Leo, approaching Regulus.

JUPITER, magnitude -2.0 , is now drawing away from the Sun and becoming visible as a brilliant morning object low in the east for a short while before dawn. Observers in the latitudes of the British Isles should not expect to see the planet until after the first week of July.

SATURN, magnitude $+0.1$, reaches opposition on July 2, when it is 1350 million kilometres from the Earth. See Figure 3, given with the notes for March, for its position. The rings of Saturn are now well open and provide a beautiful spectacle for observers with small telescopes.

On February 15 Saturn will be seen passing north of the star 28 Sagittarii ($5^m.8$). At its closest approach the separations will be only 4 arc minutes. An event of far greater interest will occur on July 3 when Saturn and its rings will pass in front of the same star. This occultation will be visible to observers in the Americas, the Pacific Ocean, and New Zealand also (partly) in Australia. All events will occur between 04^h and 11^h G.M.T. though observers may expect to see the star even when behind the rings.

VENUS AND REGULUS. There are not many first-magnitude stars sufficiently close to the ecliptic to be occulted by either the Moon or planets. One of these is Regulus, in Leo. This month Venus passes within 1.2 degrees of it, but there is no actual occultation, as last happened thirty years ago.

In 1959 the extent of Venus' atmosphere was still not well known, and in a famous book by Sir Harold Spencer Jones it had been said that in all probability the planet's atmosphere was 'less extensive' than that of the Earth. Obviously, under those circumstances, the occultation of a bright star was important. The flickering and fading of the star just before immersion, and again after emersion, would give a clue to the height of the atmosphere responsible.

The 1959 occultation occurred in the middle of the day, but it was widely observed; the Editor of this *Yearbook* used a 12-inch reflector, and the pre-occultation fading was carefully timed visually. Photoelectric measurements were made at many professional observatories. When the results were analysed, they gave a value for the obscuring atmosphere which is very similar to that found later by space-research methods.

The next occultation of Regulus by Venus will be on October 1 2044. The last occultation of a fairly bright star by Venus was that of Sigma Sagittarii on November 17, 1981.

AUGUST

New Moon: August 1 and 31

Full Moon: August 17

MERCURY reaches its greatest eastern elongation (27°) on August 29 and is visible to observers in equatorial and southern latitudes for whom it is the most suitable evening apparition of the year. Figure 6 shows, for observers in latitude $S.35^\circ$, the changes in azimuth and altitudes of Mercury on successive evenings when the Sun is 6° below the horizon. At this time of year this condition, known as the end of evening civil twilight, occurs about 30 minutes after sunset. The changes in the brightness of the planet are roughly indicated by the sizes of the circles which mark its position at five-day intervals. It will be noticed that Mercury is at its brightest before it reaches greatest eastern elongation. On August 2 its magnitude is -0.6 while it is $+0.3$ by the end of the month. Observers should note the proximity of Mars to Mercury during the first part of August.

VENUS, magnitude -4.0 , is a brilliant object in the western sky after sunset.

MARS is only 20° from the Sun at the beginning of the month and, with a magnitude of only $+1.8$, is becoming more difficult to locate by observers in the tropics; however they may see the close conjunction on August 2 when Mars passes $0^\circ.7$ N. of Regulus, which is about half a magnitude brighter than the planet. Observers outside the tropics are unlikely to see the planet again before November.

JUPITER, magnitude -2.0 , is a brilliant object in the morning skies. Jupiter is in Gemini.

SATURN, magnitude $+0.2$, continues to be visible for the greater part of the night.

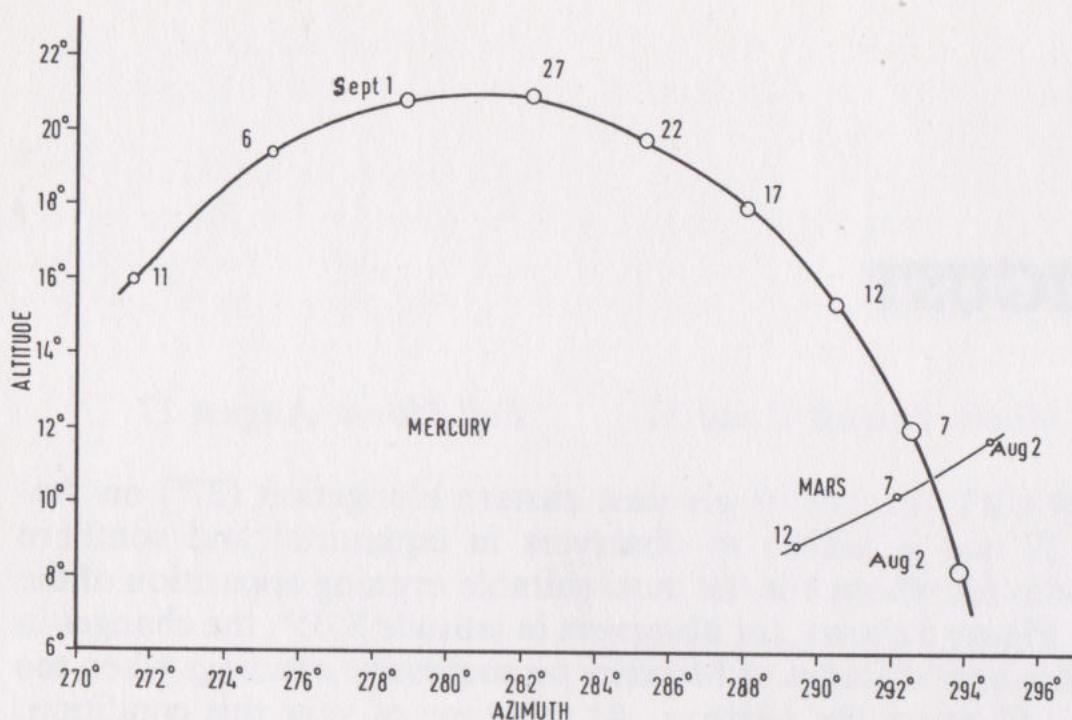


Figure 6. Evening apparition of Mercury for latitude S.35°.

VOYAGER 2 AND NEPTUNE. In every way Voyager 2 an unmanned space-craft has been one of the most spectacular of the space-probes. It was launched on August 20, 1977; it by-passed Jupiter in July 1979 and Saturn in August 1981, obtaining superb pictures as well as masses of vital data. It then went on to a rendezvous with Uranus in January 1986, again with excellent results; it has in fact provided us with virtually all our detailed knowledge about that planet. Now, in August 1989, it is scheduled to make a pass of Neptune and its system.

Neptune is the outermost giant planet; it was discovered in 1846 by Johann Galle and Heinrich D'Arrest, at the Berlin Observatory, as a result of mathematical calculations made with regard to the movements of Uranus. Now, almost a century and a half later, Neptune is to be explored by Voyager 2.

At the moment our knowledge of Neptune is fragmentary. It is slightly smaller but decidedly more massive than Uranus; unlike Uranus, it seems to have a pronounced internal heat-source, and it does not share Uranus' extraordinary axial inclination. There are two satellites, one large (Triton) and one small (Nereid). Triton has retrograde motion; Nereid has direct motion, but a very eccentric orbit which looks more cometary than planetary. Whether or not a ring exists we do not yet know. There have been

suspensions of incomplete 'ring-arcs', but the presence of a large satellite moving in a direction opposite to that of the primary's rotation must complicate matters.

At the time when these words are being written (May 1988) Voyager is on course, and functioning perfectly. There is no reason to expect that the results from Neptune will be any less striking than those already obtained by Voyager 2 from Jupiter, Saturn and Uranus. Our cover picture shows Neptune as we believe it to be; by the end of 1989 we ought to know much more. Sadly, this will be the last probe to the outer Solar System for some time, but if the Neptune pass comes up to expectations it will make 1989 a memorable year in the history of space research, and results will be reported in a future *Yearbook*.

SEPTEMBER

Full Moon: September 15

New Moon: September 29

Equinox: September 23

MERCURY is not suitably placed for observation by those in the latitudes of the British Isles. Further south the planet continues to be visible as an evening object for the first three weeks of the month and reference should be made to Figure 6 given with the notes for August.

VENUS, magnitude -4.0 , continues to be visible as a brilliant evening object in the western sky after sunset. Unfortunately for observers in the latitudes of the British Isles its southerly declination means that it is only visible for about half-an-hour each evening. On September 6 Venus passes $1^{\circ}.9$ N. of Spica.

MARS is in conjunction with the Sun on September 29 and is thus unsuitably placed for observation.

JUPITER, magnitude -2.2 , continues to be visible as a morning object and is now a conspicuous object in the night sky, rising well before midnight, as seen from northern latitudes.

SATURN, magnitude $+0.4$, remains a prominent object in the evening sky. Saturn is in Sagittarius and therefore, for observers in the northern hemisphere, poorly placed for observation when compared with oppositions occurring in winter. Observers in the British Isles, for example, never see Saturn at an altitude of more than 18° above the horizon during 1989.

FOMALHAUT. One of the smallest of Ptolemy's original forty-eight constellations is Piscis Australis or Piscis Austrinus, the Southern

Fish. It covers an area of 245 square degrees, and has only one star above the fourth magnitude, Alpha (Fomalhaut). There are six more between magnitudes 4 and $4\frac{1}{2}$, but there is no really distinctive pattern.

Fomalhaut has a declination of $29^{\circ}37' 20''$ S. This means that it is always low down as seen from Britain, and from northern Scotland it is difficult to see at all, but from England it is easy to find, as two of the stars in the Square of Pegasus point to it. (Do not confuse it with Beta Ceti, which also can be found from the Square; Beta Ceti is a magnitude fainter, and from Britain is much higher up.) Therefore, British observers never see it to advantage, but from Australia, South Africa and New Zealand it can pass near the zenith, and its brightness can be appreciated. The magnitude is 1.16.

Fomalhaut is one of our nearer neighbours, at 22 light-years; it has an A2-type spectrum, and is 13 times as luminous as the Sun. It is interesting mainly because it was one of the bright stars found by the IRAS satellite, in 1983, to have a pronounced infra-red excess, indicating the presence of cool, possibly planet-forming material. Whether or not Fomalhaut has a system of planets is not known, but certainly it cannot be ruled out. Unspectacular though it may seem to northern observers, it is certainly worth finding, and evenings in September provide good opportunities.

OCTOBER

Full moon: October 14

New Moon: October 29

Summer Time in Great Britain and Northern Ireland ends on October 29.

MERCURY reaches its greatest western elongation (18°) on October 10 and is therefore visible as a morning object except for the last week of the month.

For observers in the northern hemisphere this is the most suitable morning apparition of the year. Figure 7 shows, for observers in latitude $N.52^\circ$, the changes in azimuth and latitude of Mercury on successive mornings when the Sun is 6° below the horizon. At this time of year and in this altitude this condition, known as the beginning of morning civil twilight, occurs about 35 minutes before sunrise. The changes in the brightness of Mercury are indicated approximately by the sizes of the circles which mark its position at five-day intervals. It will be noticed that Mercury is brightest after it reaches greatest western elongation. On October 1 its magnitude is $+2.1$ and on October 26 it is -1.0 .

VENUS is a brilliant object in the early evenings, in the southwestern sky. On October 17 Venus passes $1^\circ.8$ N. of Antares.

MARS is unsuitably placed for observation.

JUPITER, magnitude -2.3 , is a brilliant morning object. It is moving slowly eastwards in Gemini, reaching a stationary point on October 29.

SATURN, magnitude $+0.5$, continues to be visible as evening object.

THE SURFACE OF MERCURY. Mercury, the innermost planet, was

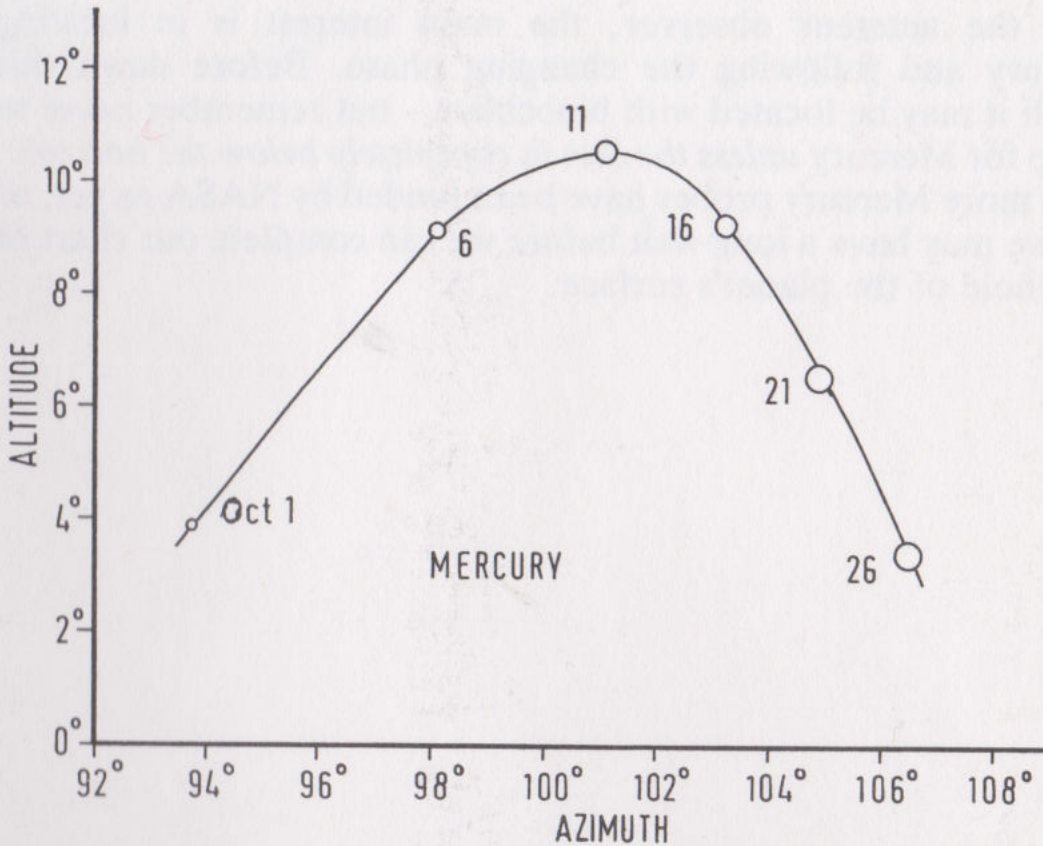


Figure 7. Morning apparition of Mercury for latitude N.52°.

appropriately named after the elusive, quick-moving Messenger of the Gods. It has been known since prehistoric times, but it is never prominent, and there must be many people who have never seen it. However, it is visible with the naked eye on a good many occasions during the year, and this October it should not be difficult to locate for northern-hemisphere observers.

Unfortunately, no telescope will show much upon its surface; after all, its diameter is only about 3000 miles, and it never comes much within 50,000,000 miles of us. E. M. Antoniadi, the most skilful planetary observer of pre-war days, used the great Meudon 33-inch refractor to draw a map of its surface features, but it has to be admitted that even Antoniadi was very wide of the mark, and his nomenclature could not be retained after the Mariner 10 passes which provided a detailed map of almost half the total surface. Mercury has craters, mountains, ridges, and intercrater plains unlike anything we see on the Moon. There is almost no atmosphere, and Antoniadi was wrong in claiming that there were 'clouds' or obscurations as pronounced as those of Mars.

To the amateur observer, the main interest is in locating Mercury and following the changing phase. Before dawn this month it may be located with binoculars – but remember *never* to sweep for Mercury *unless the Sun is completely below the horizon*.

No more Mercury probes have been funded by NASA as yet, so that we may have a long wait before we can complete our chart of the whole of the planet's surface.

NOVEMBER

Full Moon: November 13

New Moon: November 28

MERCURY passes through superior conjunction on November 10 and remains too close to the Sun for observation throughout the month.

VENUS has slowly been increasing in brightness over the last few months and is now at magnitude -4.5 . It reaches its maximum eastern elongation on November 8. The actual elongation is then $47^{\circ} 09'$, the highest value to be attained for the rest of the century. At last, for observers in the British Isles, Venus is gradually becoming visible for a little longer every evening, low on the south-western horizon: by the end of the month it is visible for nearly two hours after sunset. Venus passes 4° S. of Saturn on November 15, Venus being the brighter by 5 magnitudes.

MARS magnitude $+1.6$, is very gradually drawing away from the Sun, and by the end of the month it will be detected, albeit with difficulty, low above the south-eastern horizon before the morning sky gets too bright for observation.

JUPITER, since it reaches opposition next month, is now visible for the greater part of the night. It is moving slowly westwards in Gemini.

SATURN, magnitude $+0.6$, is still visible as an evening object but particularly for observers in northern temperate latitudes the period available for observation is decreasing rapidly as Saturn moves in towards the Sun.

SUNSPOTS AND AURORÆ. The solar cycle has an average period of about eleven years, and the next maximum is expected during the

years 1990 and 1991. Therefore, the Sun is becoming steadily more active, and this also means an increase in the numbers of auroræ or polar lights.

Auroræ are due to electrified particles sent out by the Sun, usually from flares associated with major spot-groups. These particles enter the Van Allen zones which surround the Earth, and 'overload' them; particles then cascade down into the upper air, producing auroræ. Naturally, these particles tend to be drawn to the magnetic poles, which is why auroræ are best seen from high latitudes; near the Equator they are very rare indeed (though it is on record that an aurora was once seen from Singapore). From the north of Scotland, north Norway or the Hudson's Bay area, for example, auroræ will be very common in 1989; there should be some from southern England, and possibly auroræ australis from New Zealand's South Island. It is impossible to tell just when a bright display will take place, but anyone who goes to a latitude such as that of, say, Aberdeen will be unlucky not to see auroræ on any clear night during the present winter.

DECEMBER

Full Moon: December 12

New Moon: December 28

Solstice: December 21

MERCURY attains its greatest eastern elongation (20°) on December 23 and for observers in tropical and southern latitudes it is visible as an evening object low in the western sky at the end of evening civil twilight throughout the month. Observers in the latitudes of the British Isles will find observation much more difficult and it is only between the evenings of December 25-29 that they stand much chance of locating the planet low in the south-western sky.

VENUS attains its greatest brilliancy, magnitude -4.7 , on December 14, and as it is still 40° from the Sun it dominates the sky from south-west to west in the early evenings.

MARS is now visible as a morning object, low above the south-eastern horizon before morning twilight inhibits observation. Mars passes 5°N. of Antares on December 30 when the planet, magnitude $+1.6$, is about half a magnitude fainter than the star.

JUPITER, magnitude -2.7 , is at opposition on December 27 and therefore visible throughout the night. Its distance from the Earth will then be 623 million kilometres. Now is a convenient time for those observers with binoculars to see if they can detect the four Galilean satellites of the planet.

SATURN is coming to the end of its period of visibility. Observers in the latitudes of the British Isles are unlikely to see the planet after the first week of December. Further south, observers may manage a further week of visibility.

THE GALILEAN SATELLITES. Jupiter's satellite family is unlike any other in the Solar System. There are four large satellites, while the remainder are very small. The major members of the system were observed by Galileo in January 1610, with his primitive 'optick tube', and they are always known as the Galileans, even though Galileo may not have been the first to see them. Io is slightly larger than our Moon, Europa slightly smaller, and Ganymede and Callisto much larger; indeed, Ganymede is larger than the planet Mercury, though not so massive.

But for the glare of Jupiter itself, all the Galileans would be naked-eye objects; the magnitudes range from about 4.6 (Ganymede) to 5.6 (Callisto, the least reflective of the four). There is good evidence that one of them, probably Ganymede, was seen with the naked eye by a Chinese observer named Gan De, as long ago as the year BC 364. Good binoculars should show them, and with any good small telescope they are very conspicuous.

They are not alike. The Voyagers have shown us that Ganymede and Callisto are icy and cratered, Europa icy and smooth, and Io red and actively volcanic. Yet with an ordinary telescope it is not easy to see any colour in Io, and it may be that there are changes from year to year, because there is no doubt that violent eruptions are taking place there all the time. Of the rest, Ganymede is always easy to identify, because it is so much the brightest.

We are still not sure why the four are so dissimilar; nothing of the sort had been expected. And as one eminent astronomer has commented, 'there is no such thing as an uninteresting Galilean'.

Eclipses in 1989

In 1989 there will be four eclipses, two of the Sun, and two of the moon.

1. A total eclipse of the Moon on February 20 is visible from the north-western part of North America, the Arctic regions, Australasia, Asia, the extreme eastern part of Africa and the north-eastern part of Europe. The eclipse begins at 13^h 45^m and ends at 17^h 27^m. Totality lasts from 14^h 57^m to 16^h 15^m.
2. A partial eclipse of the Sun on March 7 is visible from the Hawaiian Islands, the eastern part of the North Pacific Ocean, the north-western half of North America, most of Greenland, the extreme north-eastern part of Asia and the arctic regions. The eclipse begins at 16^h 17^m and ends at 19^h 58^m. The time of maximum eclipse is 18^h 07^m, when 0.83 of the Sun's diameter is obscured.
3. A total eclipse of the Moon on August 17 is visible from the extreme western part of Asia, Europe (including the British Isles) but excluding the northern part of Scandinavia, Africa, Iceland, Greenland except the northern part, the Americas except the north-western part of North America, and most of Antarctica. The eclipse begins at 01^h 21^m and ends at 04^h 55^m. Totality lasts from 02^h 20^m to 03^h 56^m.
4. A partial eclipse of the Sun on August 31 is visible from the extreme south-east of Africa, Madagascar, part of Antarctica and the southern part of the Indian Ocean. The eclipse begins at 03^h 34^m and ends at 07^h 28^m. The time of maximum eclipse is 05^h 30^m, when 0.63 of the Sun's diameter is obscured.

Occultations in 1989

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than five degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about twenty degrees a year, a complete revolution taking 18.6 years, during which time all the stars that lie within about six and a half degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star but only a few of these occultations will be visible at any one place in hours of darkness.

There are six occultations of planets in 1989, two of Mercury, three of Venus and one of Mars. None of these is visible from Great Britain or North America.

Only four first-magnitude stars are near enough to the ecliptic to be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares. No occultations of these stars are visible from Great Britain in 1989.

Predictions of these occultations are made on a world-wide basis for all stars down to magnitude 7.5, and sometimes even fainter. Lunar occultations of radio sources are also of interest – remember that the first quasar, 3C.273, was discovered as the result of an occultation.

Recently occultations of stars by planets (including minor planets) and satellites have aroused considerable attention.

The exact timing of such events gives valuable information about positions, sizes, orbits, atmospheres and sometimes of the presence of satellites. The discovery of the rings of Uranus in 1977 was the unexpected result of the observations made of a predicted occultation of a faint star by Uranus. The duration of an occultation by a satellite or minor planet is quite small (usually of the order of a minute or less). If observations are made from a number of stations it is possible to deduce the size of the planet.

The observations need to be made either photoelectrically or visually. The high accuracy of the method can readily be appreci-

ated when one realizes that even a stop-watch timing accurate to 0^s.1 is, on average, equivalent to an accuracy of about 1 kilometre in the chord measured across the minor planet.

Comets in 1989

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space.

Comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the Earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The following periodic comets are expected to return to perihelion in 1989:

<i>Comet</i>	<i>Year of discovery</i>	<i>Period (years)</i>	<i>Predicted date of perihelion 1989</i>
Tempel (1)	1867	5.5	Jan. 4
D'Arrest	1851	6.4	Feb. 4
Churyumov-Gerasimenko	1969	6.6	June 18
Pons-Winnecke	1819	6.4	Aug. 19
Gunn	1970	6.8	Sept. 24
Brorsen-Metcalf	1847	70.6	Sept. 27
Lovas 1	1980	9.1	Oct. 10
du Toit-Neujmin-Delforte	1941	6.4	Oct. 18
Schwassmann-Wachmann (1)	1927	14.8	Oct. 26
Gehrels 2	1973	7.9	Nov. 3
Clark	1973	5.5	Nov. 28

Minor Planets in 1989

Although many thousands of minor planets (asteroids) are known to exist, only 3,000 of these have well-determined orbits and are listed in the catalogues. Most of these orbits lie entirely between the orbits of Mars and Jupiter. All of these bodies are quite small, and even the largest, Ceres, is believed to be only about 1,000 kilometres in diameter. Thus, they are necessarily faint objects, and although a number of them are within the reach of a small telescope few of them ever reach any considerable brightness. The first four that were discovered are named Ceres, Pallas, Juno and Vesta. Actually the largest four minor planets are Ceres, Pallas, Vesta and Hygiea. Vesta can occasionally be seen with the naked eye and this is most likely to occur when an opposition occurs near June, since Vesta would then be at perihelion. In 1989 Ceres will be at opposition on December 20 (magnitude 6.7), Pallas on September 30 (magnitude 8.2) Juno on February 21 (magnitude 8.6) and Vesta on June 26 (magnitude 5.3).

A vigorous campaign for observing the occultations of stars by the minor planets has produced improved values for the dimensions of some of them, as well as the suggestion that some of these planets may be accompanied by satellites. Many of these observations have been made photoelectrically. However, amateur observers have found renewed interest in the minor planets since it has been shown that their visual timings of an occultation of a star by a minor planet are accurate enough to lead to reliable determinations of diameter (see page 104). As a consequence many groups of observers all over the world are now organizing themselves for expeditions should the predicted track of such an occultation cross their country.

In 1984 the British Astronomical Association formed a special Minor Planet Section.

Meteors in 1989

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect a concentration of meteoric dust moving in an orbit around the Sun. If the dust is well spread out in space, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors been so numerous as to resemble snowflakes falling.

If the meteor tracks are marked on a star map and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers with their radiants; interference by moonlight is shown by the letter M.

<i>Limiting dates</i>	<i>Shower</i>	<i>Maximum</i>	<i>R.A. Dec.</i>
Jan. 1-6	Quadrantids	Jan. 3	15 ^h 28 ^m +50°
April 20-22	Lyrids	April. 22	18 ^h 08 ^m +32° M
May 1-5	Aquarids	May 5	22 ^h 20 ^m +00°
June 17-26	Ophiuchids	June 20	17 ^h 20 ^m –20° M
July 15-Aug.15	Delta Aquarids	July 29	22 ^h 36 ^m –17°
July 15-Aug.20	Piscis Australids	July 31	22 ^h 40 ^m –30°
July 15-Aug.25	Capricornids	Aug. 2	20 ^h 36 ^m –10°
July 23-Aug.20	Perseids	Aug. 12	3 ^h 04 ^m +58° M
Oct. 15-25	Orionids	Oct. 22	6 ^h 24 ^m +15° M
Oct. 20-Nov.30	Taurids	Nov. 3	3 ^h 44 ^m +14°
Nov. 15-19	Leonids	Nov. 17	10 ^h 08 ^m +22° M
Dec. 9-14	Geminids	Dec. 13	7 ^h 28 ^m +32° M
Dec. 17-24	Ursids	Dec. 22	14 ^h 28 ^m +78°

M=moonlight interferes

Some Events in 1990

ECLIPSES

In 1990 there will be four eclipses, two of the Sun and two of the Moon.

January 26: annular eclipse of the Sun – south of New Zealand, Antarctica, S. America (except N.W.).

February 9: total eclipse of the Moon – N.W. Alaska, arctic regions, Australasia, Asia, Africa, Europe, Iceland, Greenland.

July 22: total eclipse of the Sun – N.E. Europe, N. of Greenland, N. Asia, Arctic regions, N.W. of N. America, Hawaiian Islands.

August 6: partial eclipse of the Moon – S.W. Alaska, Pacific Ocean, Antarctica, Australasia, S. and E. Asia.

THE PLANETS

Mercury may be seen more easily from northern latitudes in the evenings about the time of greatest eastern elongation (April 13) and in the mornings around greatest western elongation (September 24). In the southern hemisphere the corresponding dates are February 1 (mornings) and August 11 (evenings). *Venus* is visible in the evenings for the first part of January. From late in January until late in September it is visible in the mornings. It is again visible in the evenings for the second half of December.

Mars is a morning object until opposition on November 27: thereafter it is an evening object.

Jupiter is not at opposition until 1991 January 29

Saturn is at opposition on July 14

Uranus is at opposition on June 29

Neptune is at opposition on July 5

Pluto is at opposition on May 7

The Lunar Surface

GILBERT FIELDER

It is illuminating to have viewed the dark and light materials of the Moon both before, and after, the spate of lunar landings which started in the 1960s. Prior to the direct analysis of lunar rocks, speculations on the physical nature of the lunar surface ranged from those about hard rocks to underdense dust; from those about indurated lavas to impact rubble. After the meticulous analyses of returned lunar surface materials, significant inroads were made towards the resolution of conflicting views about the nature and origin of the Moon. At the same time, the Moon emerged as an unexpectedly complex body that had undergone a great deal of upheaval in its long development over 4.6 Ga. (Ga = gigayears = 10^9 years.)

On the Earth, rocks may be classed as igneous, sedimentary or metamorphic. In common with the Earth, the Moon sports an abundance of igneous rocks; but it has no water-laid sediments. Instead, the fragmental lunar surface layer may be termed a regolith. The regolith (Figure 1) is constituted of a wide range of particle sizes, from dust to marble sizes, and, less frequently (and depending on definition), much bigger than marble sizes. In thickness, these low-compaction layers may be up to several metres deep. The third main class of rock found on the surface of the Moon is breccia (Figure 2) – a rock consisting of particles cemented or welded together to a greater or lesser extent.

Sampling

It is tempting to talk about the lunar rocks as if we were familiar with the geology of all parts of the Moon in some detail. This is far from true, since all the soft-landers have touched down on the near side of the Moon and the vast majority of the rocks which have been fully analysed were from mare-type (darker) regions of the Moon. Early in the programme of soft-landing missions, however, it was realized that, even in the maria, some lighter-toned 'exotic' samples (Figure 3) were being recovered from the regolith. It is now generally agreed that these samples – which dating methods

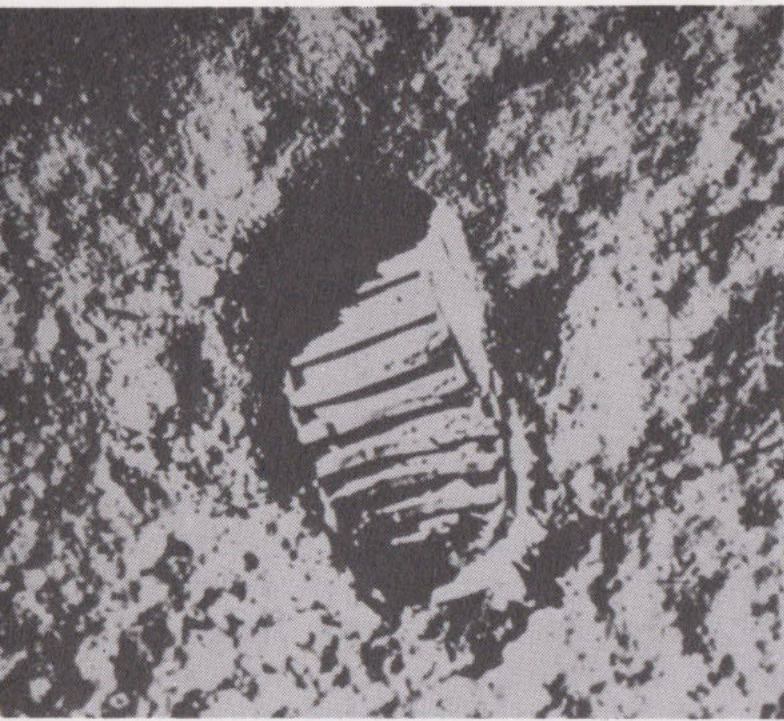
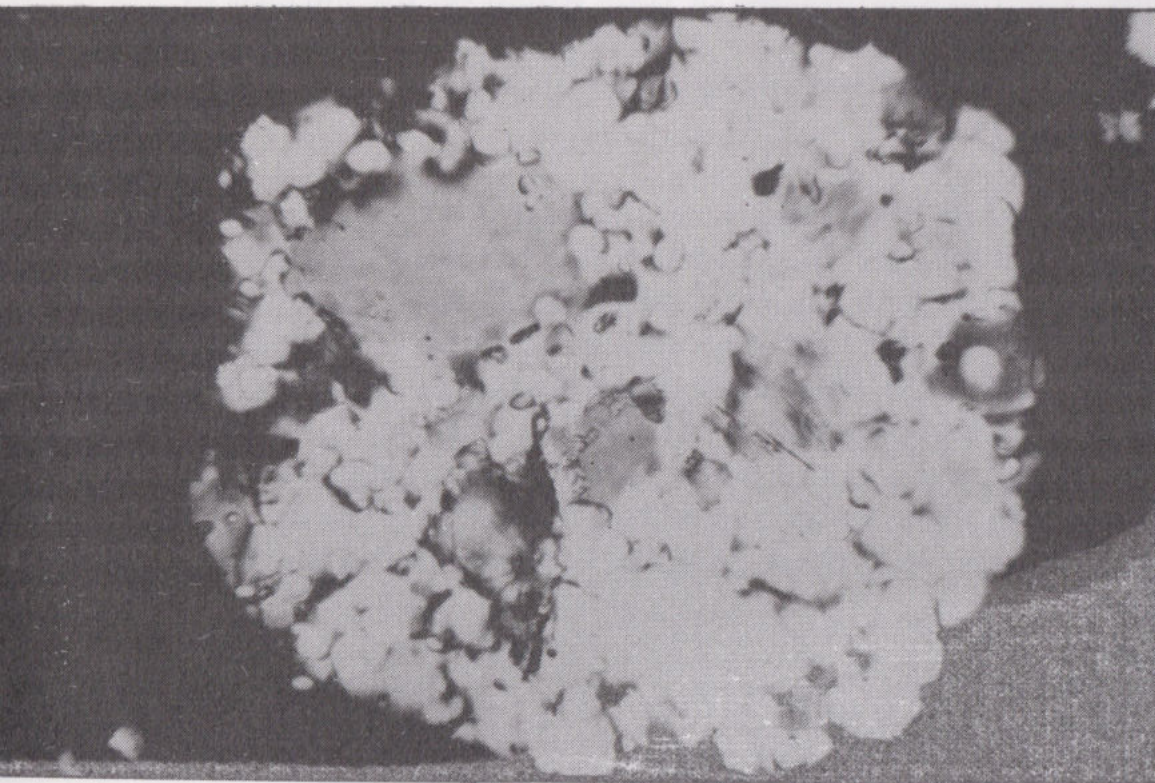


Figure 1. Close up of the lunar soil. The indentation made by an Apollo 11 astronaut's boot may be used to judge the physical character of the regolith. (NASA)

Figure 2. A breccia, returned to Earth by the Apollo 16 astronauts, which is clearly composed of a variety of rocks.



Figure 3. A thin section of a piece of anorthosite from the Moon.



proved to be older than the bulk of the mare samples – were, at some time, ejected from the brighter highlands as a result of impacts which showered material to other parts of the Moon. So the sampling of the lunar surface, although not good, is more representative than one might, on first thoughts, have supposed.

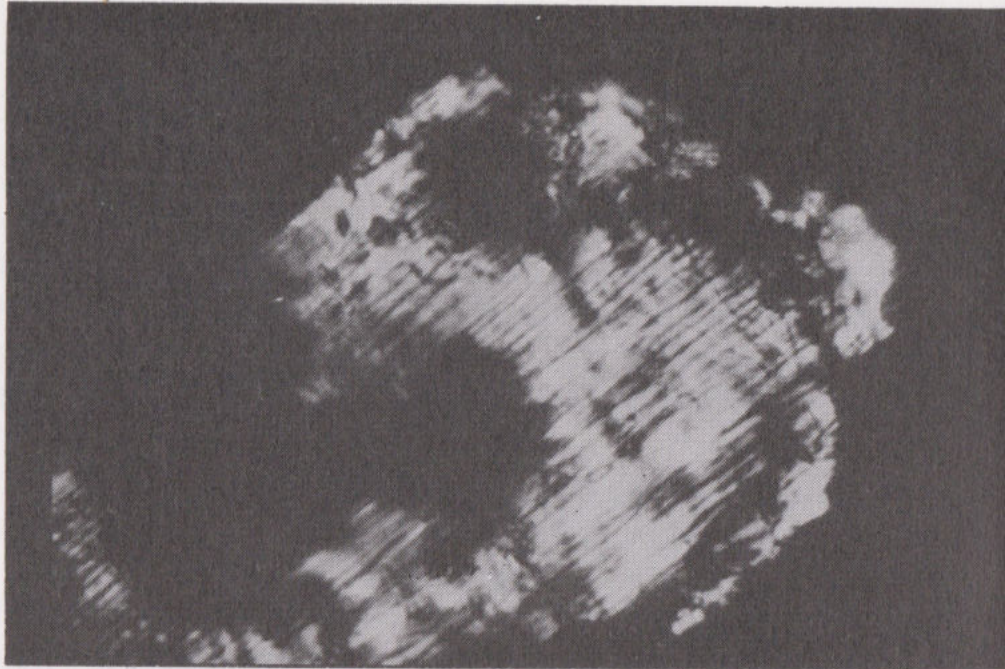
Formation of the Breccias and the Regolith

Breccias were formed when other rock particles having a variety of origins were brought together and cemented and/or metamorphosed in the process. The other rock particles derived, essentially, from the regolith. Cementation may have come about as a result of the pressure of the overburden (overlying rocks). In that case, to appear on the surface the breccias would have to have been excavated from some depth by a natural event such as an impact of a meteoroid or a volcanic upheaval. Or, in principle, the cementing of the particles may have been the result of a heating process. Stronger cementation, or welding, arose in shock processes: the evidence (Figure 4) for these processes is unambiguous in the case of many breccias.

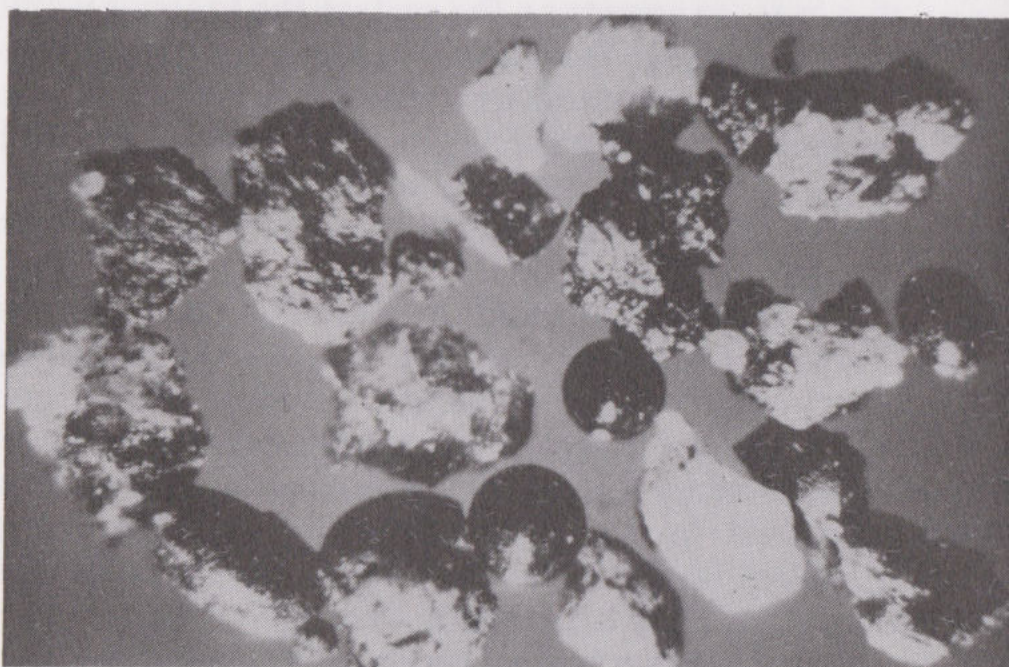
Shock welding could in principle have originated in lunar volcanic explosions, but it is possible to reproduce the signs of shock which are in evidence in many of the crystals of lunar breccias, for example. When such experiments are conducted in the laboratory it is also possible to estimate the peak temperatures generated in a shocked material and, also, the peak shock pressures in that material. These peak pressures are higher than one might have expected in volcanic vents.

In the relevant impact process, the kinetic energy of a meteoroid is transferred to the Moon's surface. A shock front passes down into the Moon while another shock travels backwards into the meteoroid. Initially, material in front of the impacting meteoroid is compressed into a lens-shape and most of the compressed particles move downwards. Typically, pressures of a few million bars ($1 \text{ bar} = 1 \text{ atmosphere} = 10^5 \text{ N m}^{-2}$) are generated. At this stage in the process the stresses induced in the target materials are one thousand to ten thousand times greater than the strength of those materials. For that reason, the compressed materials flow like fluids – they behave hydrodynamically. Understandably, the unrestrained surfaces of the meteoroid and Moon are unable to sustain the high pressures. Rarefaction waves develop and hot, fluid (liquid and gaseous) matter is ejected at very high velocities

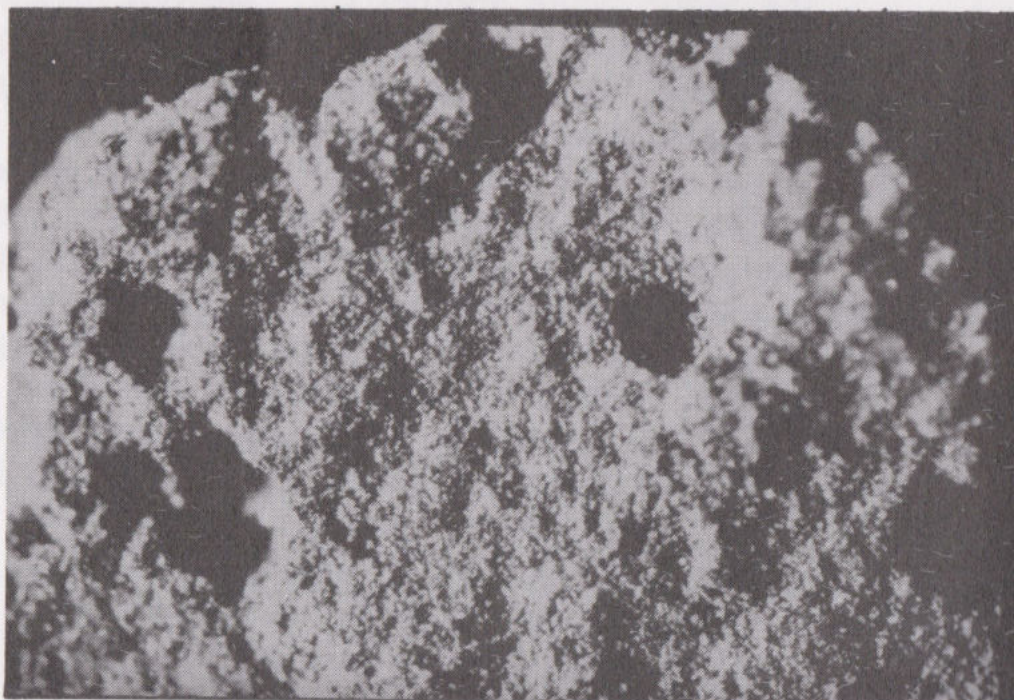
*Figure 4. Shock
Lamellae in a lunar
pyroxene crystal.*



*Figure 5. A variety of
particles from the
lunar regolith. The
glass beads shown
here are less than
0.5mm in diameter.*



*Figure 6. Part of a
piece of fine-grained
basalt (about 2mm x
3mm) from the
Moon. Before this
basalt finally
congealed, bubbles of
gas punctured the
surface, at the dark
spots seen here, and
escaped from it.*



and at low angles to the horizontal. Following this jetting process, shocked material moves outwards from the initial crater. Most of this shocked material is destined to form breccias, or, otherwise, contribute to the particulate regolith.

In fact, the regolith contains not only shocked and unshocked fragments but, also, many rotational shapes made of glass (Figure 5). Glassy rocks are made by melting a rock and then chilling it rapidly. Both impact and volcanism are able to provide the melting. Rotational shapes, which may be spherical, ellipsoidal or even dumb-bell-shaped, are produced when small, liquid drops are chilled during free fall above the Moon's surface. In total, the regolith consists of fragments of all other rocks found on the Moon, either uncemented or welded as breccias, together with a little metallic iron. It is most likely that the iron derives from meteoroids.

The processes of impact fragmentation of solid pieces of rock, and of impact gardening – re-working of extant regolith materials by repeated impacts – is clearly of importance in the formation of the regolith. However, there is also evidence for volcanic contributions to the regolith, and the importance of past pyroclastic activity on the Moon as a contributor to the regolith should not be excluded.

Igneous Rocks

The bulk of the regolith and breccias derived from rocks that were laid down earlier. These are the lunar igneous rocks. They divide into the lighter-toned anorthosites (see Figure 3) – the rock type of the highlands – and the darker basalts (Figure 6). The broad distinction is clear to the unaided eye, especially at time of full Moon. In general, both these major rock types contain the minerals plagioclase and pyroxene. In terms of chemical symbols, plagioclases are composed of the elements Ca, Na, Al, Si and O, and pyroxenes are based on Ca, Fe, Mg, Si and O. Additionally, anorthosites may contain olivine, $(\text{Mg,Fe})_2\text{SiO}_4$, while the lunar basalts were found to contain characteristic amounts of ilmenite, consisting of the elements Fe, Ti and O. Cristobalite (SiO_2) is another common mineral in the lunar igneous rocks.

Both the basalts and the anorthosites differ chemically from those of the Earth. All igneous rocks which have cooled slowly from a melt are crystalline. Depending on their conditions of origin, such rocks may be coarse-grained or fine-grained. The

coarse-grained lunar basalts and anorthosites cannot have formed at the lunar surface but must have cooled slowly and must have derived from melts at considerable depths where differentiation was involved. Some other basalts might be from impact melts. However, the most important findings from studies of the lunar igneous rocks is that they suffered a protracted history of differentiation and that, for the anorthosites and related rocks of the present highlands of the Moon, this dynamic process of differentiation was in full swing very early in lunar history. The bright highlands of the Moon, modified by volcanism and impacts since they were carried to the surface by convective processes, point unerringly to the conclusion that the interior of the Moon was hot and active earlier than 4.5 Ga ago.

The lavas of the maria poured out from volcanic vents and fissures very much later in the Moon's history. Dating of returned samples indicated that many of the lavas cooled only 3.2 to 3.8 Ga ago. Indeed, these lavas are observed to overlap the highland rocks. Interestingly, there is photogeological evidence for much more recent lunar volcanic activity than that. The overall development of the Moon is intriguingly complex. Happily, a close look at surface samples has settled a number of arguments. The mare melts were created by – or, at least, helped by – radioactive heating. But what have we learned about the process or processes that heated the newly forming Moon? A generally agreed answer to that question is still awaited.

Acknowledgements

The author is grateful for permission to reproduce Figures 3-6 which were taken from *Lunar Rocks under the Microscope – Glasses, Rocks and Minerals* by Professor von Engelhardt and Dr Stöffler, published by Carl Zeiss, Oberkochen, West Germany.

The Volcanoes of Venus

PETER CATTERMOLÉ

The planet Venus is in many ways like the Earth, yet in spite of many similarities and its relative proximity, it remained largely an enigma until powerful Earth-based radar transmitters and radar-bearing space-craft began to probe beneath its dense, choking atmosphere. Only in 1962 was it established by radar measurements, what was the rotation period of the solid planet, and no-one appears to have suspected that it had a retrograde motion much longer than the 4-day prograde rotation of the upper atmosphere. Insights into what lay beneath this opaque layer of predominantly carbon dioxide and sulphur compounds have come mainly from Pioneer and Venera space-craft, and from probings made with giant radar telescopes, such as that at Arecibo in Puerto Rico. While the surface is generally quite subdued, there is at least one deep graben-like valley not dissimilar to the Earth's East African Rift, several high continent-sized regions of which parts are traversed by strange ridge-and-trough terrain, one large basin over 1000 km in diameter, craters in abundance and, last but not least, several giant volcanoes, some of which recently may have been active!

Strangely enough, the very permanence of the opaque clouds is circumstantial evidence that active volcanism may be a characteristic of Venus. The clouds themselves are composed of sulphuric acid and a material that absorbs ultra-violet radiation; this is probably elemental sulphur. During the last decade various probes have survived descent through this corrosive layer which sits between 50 and 70 km above the surface, and have been able to measure the composition both of the atmosphere and the solid crust. As a result, it has been possible to construct a model for how the two interact in complicated photochemical and thermochemical cycles that transform sulphurous gases into cloud particles. The information appears to indicate that sulphur gas is continually being injected into the atmosphere, and the only feasible mechanism that can accomplish this is volcanism. Changes in the amounts of sulphur dioxide above the cloud tops recorded by Pioneer

Venus as it orbited the planet, were of the same type known to have occurred during the March 1982 eruption of the Mexican volcano, El Chichón, and suggest that Venus has been wracked by massive eruptions during the very recent past.

The topography of Venus is now quite well known. There are two large continent-sized upland regions and a number of smaller upland massifs which make up about 8 per cent of the surface. The larger regions are called Aphrodite Terra, which sits along the planet's equator, and Ishtar Terra, which lies north of latitude 60 degrees. Of the smaller massifs, Beta Regio is the most striking. The highest point is Maxwell Montes, situated in the continental region known as Ishtar Terra (Figure 1). Maxwell Montes lies 11.1 km above datum. The deepest trough lies in the floor of a large rift valley, Diana Chasma, which is deeper than the bottom of the Red Sea and thrusts 4 km down into another continental massif, Aphrodite Terra which sits astride Venus' equator. A further 65 per cent is given over to upland rolling plains which were first recognized with the Goldstone telescope, and which are pock-marked with numerous large (500–800 km) circular features which could either be impact or volcanic in origin. Roughly 20 per cent of the remaining surface is lowland, one of the most extensive lowland tracts being Guinevere Planitia which has a decidedly rectilinear aspect, as if its outline were controlled by pre-existing fault lines.

One of the most interesting of the potential volcanic regions lies in Beta Regio, and comprises the two mountain massifs called Rhea and Theia Montes. As long ago as 1977 Saunders and Malin of the Jet Propulsion Laboratory suggested that Theia Mons was a giant shield volcano, similar in general form to a Hawaiian volcano such as Mauna Loa. Theia Mons is over 4.5 km high and 700 km in diameter and has a radar-dark circular feature at its summit, believed to be a caldera depression. While it is substantially larger than any Hawaiian shield, in general form it is very similar. It appears to be positioned on a broad dome in the crust which may make it seem somewhat larger than it really is, the evidence for this coming from gravity data collected by Pioneer Venus. This was analysed by George McGill of Massachusetts Institute of Technology, who observed that the very strong gravity located beneath the feature could be the result of regional upwelling of magma, perhaps sufficient to cause lateral movement in the crust. More recent Arecibo radar mapping indicates that the structure

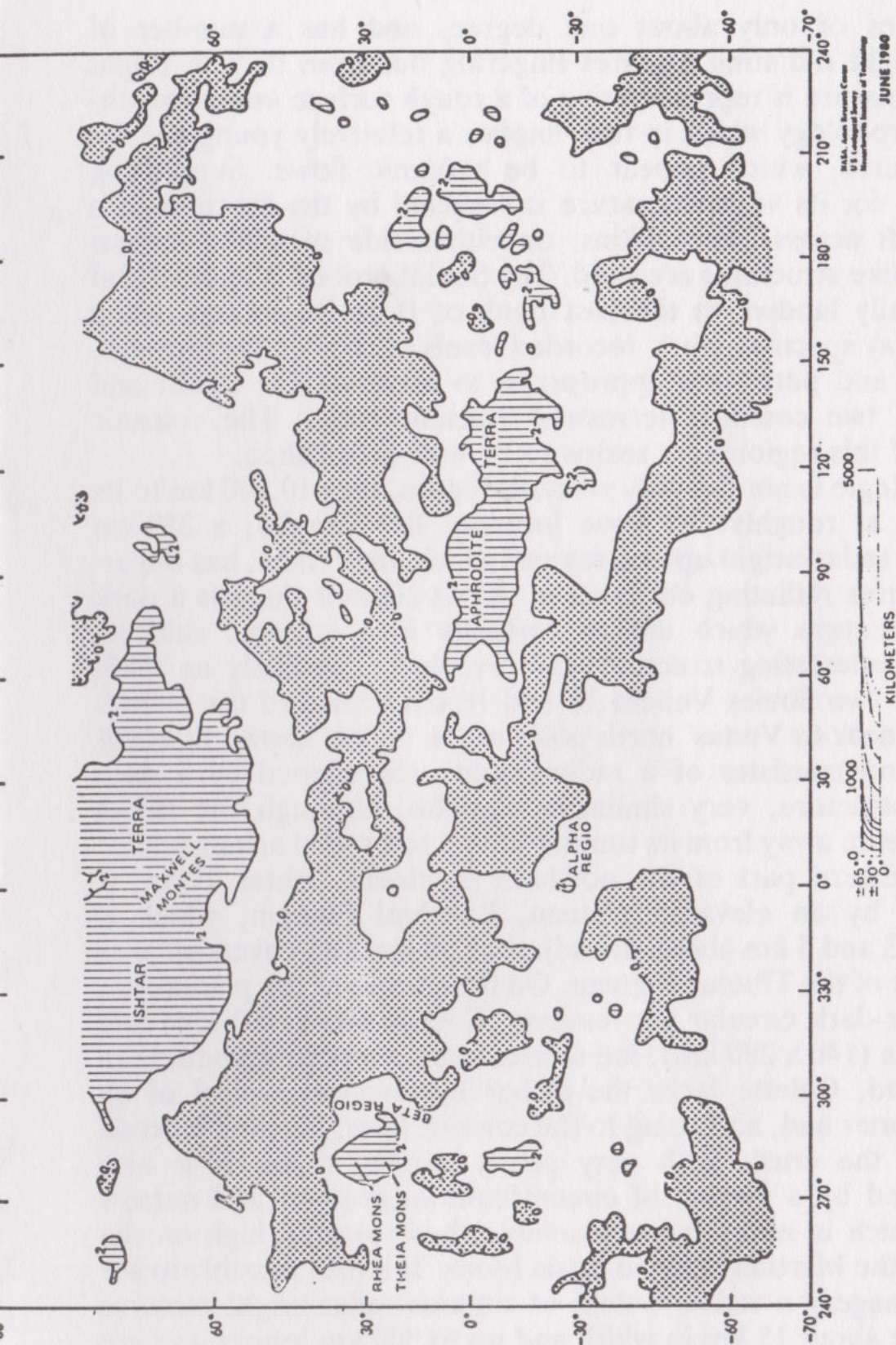


Figure 1. Topographic Provinces of Venus. Map showing distribution of topographic provinces on Venus: rolling plains (no pattern), 0 (6051.0) to 2 km (6053.0); highlands (hatching), higher than 2 km (6053.0-6062.1); and lowlands (dotted pattern), lower than 0 km (6049.0-6051.0). The numbers in parentheses are planetary radii in kilometers.

has slopes of only about one degree, and has a number of radar-bright radiating features fingering out from it. The bright radar signature is representative of a rough surface and unweathered morphology which in turn implies a relatively young age for the features, which appear to be volcanic flows. Supporting evidence for its volcanic nature is supplied by the location of a major rift across Theia Mons, on either side of which several volcano-like structures are sited. The Soviet probes, Venera 9 and 10, actually landed on the east flank of Beta Regio and, using gamma-ray spectrometers, recorded levels of radioactive thorium, uranium and potassium appropriate to alkali-olivine basalt and tholeiite, two common terrestrial volcanic rocks. The volcanic nature of this region now seems to be well established.

Beta Regio is not the only volcanic region, thus 10,000 km to its east and at roughly the same latitude, lies Sappho, a 250-km diameter radar-bright upland feature which, like Theia, has finger-like features radiating out from it. At its summit there is a dark circular feature which almost certainly is a volcanic caldera. Another interesting structure was revealed as recently as 1983, when the two Soviet Venera 15 and 16 craft reached the planet. This lies near to Venus' north pole, in the region known as Metis Regio, and consists of a radar-bright area capped by a dark caldera structure, very similar to Sappho, although the ridges which stream away from its summit have a less radial arrangement.

The western part of the northern continent, Ishtar Terra, is occupied by an elevated plateau, Lakshmi Planum, which is between 3 and 5 km above the adjacent plains, and covers an area twice that of the Tibetan Plateau. On the surface of the plateau are two radar-dark circular depressions, Colette (80 x 120 km) and Sacajawea (140 x 280 km), the former being more prominent than the second. Colette lacks the rather narrow rim typical of an impact crater and, according to the contour lines, sits atop a broad dome in the crust, with very gently sloping sides. It is also surrounded by a system of circumferential grooves and narrow ridges which in many facets resemble those located high on the flanks of the Martian volcano Arsia Mons. It is also possible to see on the imagery a radial system of sinuous radar-bright features which are about 15 km in width and up to 300 km long; these are presumed to be long lava flows. Colette, therefore, is considered to be another volcanic caldera and its companion, Sacajawea, is almost certainly an older version of the same thing.

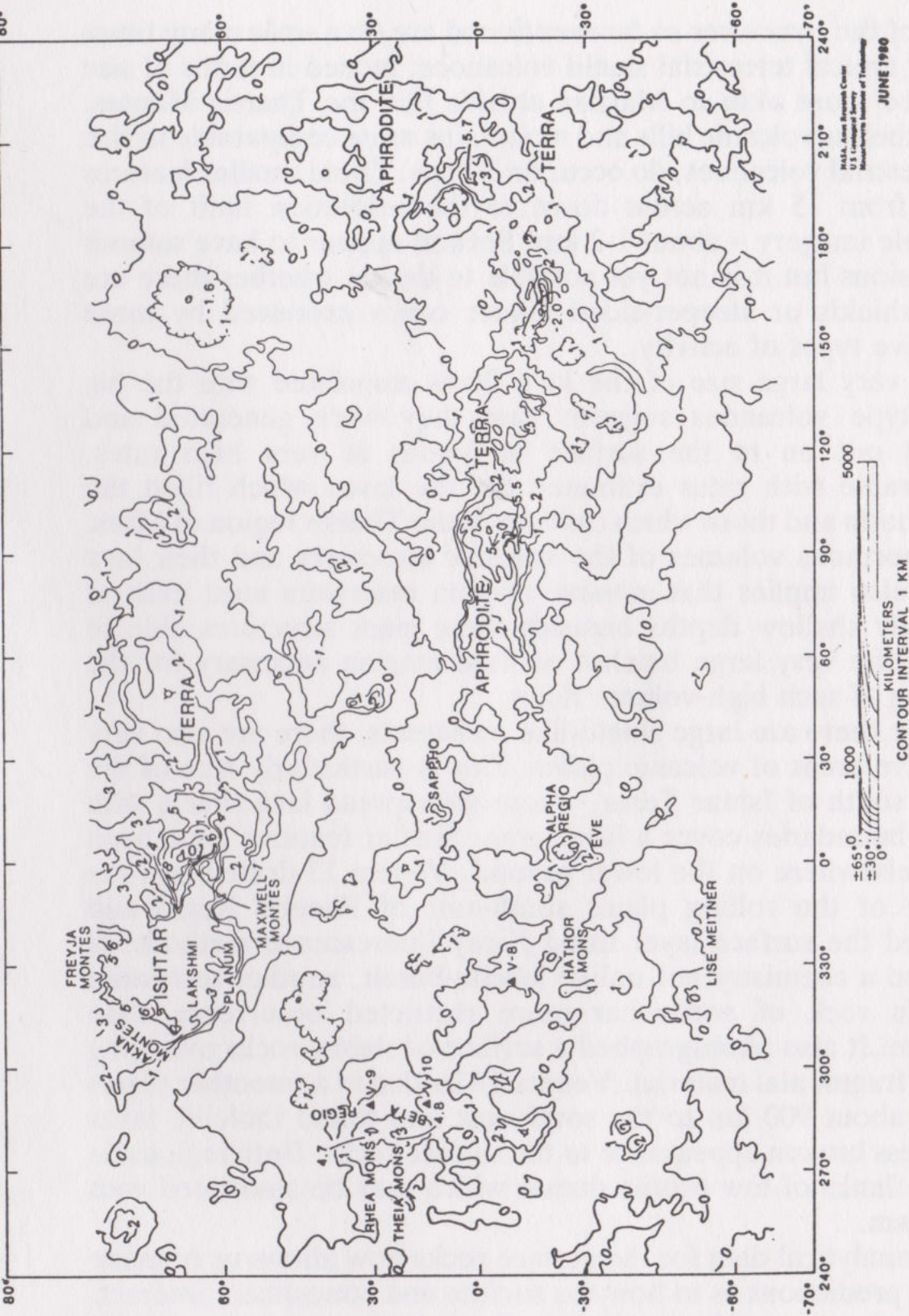


Figure 2. Contour Map of Venus. Generalized topographic map of Venus showing elevations of surface features. Contour interval is 1.0 km. The highest point (6062.1 km) is the summit of Maxwell Montes, the radar-bright feature centred at latitude 63.8°N, longitude 2.2°. The lowest point (6049.0 km) is within the rift valley named Diana Chasma at latitude 14°S, longitude 156°. V-8, V-9, and V-10 show locations of the USSR Venera 8, 9, and 10 landers.

All of the structures so far mentioned are on a scale many times that of typical terrestrial shield volcanoes; indeed in terms of size they are more akin to Martian shields like the Tharsis Montes. Nevertheless volcanic hills and mountains more comparable in size to terrestrial volcanoes, do occur on Venus. These smaller features range from 15 km across down to the resolution limit of the available imagery – about 1-2 km. Several appear to have summit depressions but it is not yet possible to decide whether these are small shields or steeper-sided cinder cones produced by more explosive types of activity.

The very large size of the lava flows associated with the big shield-type volcanoes suggests that they were generated and poured out on to the surface of Venus at very high rates, comparable with rates estimated for the lavas which filled the lunar maria and those which outcrop in the Tharsis region of Mars. The enormous volumes of the volcanic structures and their lava flows, also implies that massive magma reservoirs must exist at relatively shallow depths beneath these giant structures able to deliver the very large batches of fluid magma necessary for the building of such high-volume flows.

While there are large shield-like constructs, there are also very extensive areas of volcanic plains. This is particularly true of the region south of Ishtar Terra, where widespread lava sheets with lobate boundaries cover a large area. Similar features have been found elsewhere on the lower ground. Venera 13 drilled into the surface of the rolling plains south-east of Phoebe Regio and analysed the surface layer using X-ray fluorescence methods. It revealed a chemistry not unlike leucite-basalt, another terrestrial volcanic rock of somewhat more restricted occurrence than tholeiite. It also photographed a surface of slabby rocks overlying darker fragmental material. Venera 14 landed in a smoother plains region about 900 km to the south-east and found tholeiite lavas and a less broken appearance to the surface rocks. Both regions lie on the flanks of low profile domes which may be associated with volcanism.

The analytical data for the surface rocks now allows us to make certain predictions as to how the surface and atmosphere interact. Soviet scientists at the Vernadsky Institute have determined the elemental composition of the planet's crust and while the rocks are all basaltic, they also contain a relatively large amount of calcium and amounts of sulphur much greater than in similar terrestrial

basalts, although less abundant than the calcium. This indicates that most of the calcium must reside in silicate and carbonate minerals, presumably in the form of oxides, not sulphates. This means that calcium oxide must be available to react freely with sulphur dioxide in the atmosphere which must, therefore, be draining from the atmosphere at the present time, into a kind of calcium oxide 'sink'. This poses a problem, because currently sulphur dioxide is present in the atmosphere at ten times the equilibrium mixing ratio predicted by theory, in which case sulphur must have been injected into the atmosphere in geologically very recent times. One very obvious source for all this sulphur would be the common mineral pyrite (iron sulphide) which, if it occurred at the surface of lava flows, could react with the atmosphere, giving off sulphur gases. Another possibility is for similar reactions to take place below the surface, the gases then being ejected into the atmosphere during volcanic eruptions. Interestingly two American scientists, Pettengill and Ford of MIT, recently have presented indirect evidence for the existence of pyrite on the surface of Beta Regio. The evidence comes from an observation that this region is many times more reflective than the surrounding plains. This in turn implies that the surface rocks have much higher electrical conductivity, which remarkably few rocks do. Of those which could explain the reflectivity data, lavas with abundant inclusions of highly conductive pyrite best fit the bill. Such materials could only be produced by relatively recent volcanism or the weathering of older, pyrite-bearing volcanic deposits.

In itself this does not prove that volcanic activity is actually occurring at the present time; however, there have been other surprising discoveries which hint that such is the case. The 1982 eruption of El Chichón sent vast amounts of sulphur particles into the Earth's atmosphere, and these remained there for several years. If similar activity has occurred recently on Venus, then this too should have left some atmospheric signature. Larry Esposito of the University of Colorado, in analysing the Pioneer Venus data, reported that levels of sulphur dioxide and sulphuric acid haze in the atmosphere of Venus dropped by about 90 per cent between the years 1978 and 1983. The 1978 levels themselves had been well above those predicted after studies of Venus from the Earth over the previous fifteen years, and, as a consequence, Esposito predicted that large-scale volcanic eruptions must have occurred during the late 1970s, sending sulphur dioxide high into

the clouds. Eventually this would have been converted into sulphuric acid, later to settle back into the lower atmosphere.

Another piece of circumstantial evidence comes from observations by Fred Scarf and co-workers who, in 1983, reported that a space-craft antenna had picked up radio emissions on low frequencies. The radio bursts interestingly were clustered above several predicted volcanic regions, such as Beta Regio and Phoebe Regio – an upland massif to its south – and over Alpha Regio, a suspected volcanic massif at the eastern end of Aphrodite Terra. They are most readily interpreted as being produced by violent lightning discharges, which have often been recorded in the plumes of erupting volcanoes on the Earth, and there is no contrary evidence to suggest that the same should not be true of Venus.

While no-one to date has seen an active volcano on Venus, it can safely be said that in the light of recent images obtained, of chemical analyses returned from lander probes, and of observations regarding atmospheric sulphur levels and localized radio bursts, that the evidence for active volcanicity on Venus is strong. Furthermore if such is the case, this gives scientists an important clue as to how the surface and atmosphere interact to produce the clouds. Whatever may be the details of volcanic processes on the planet, there seems little doubt that Venus, like the Earth, is a geologically active world.

A Bang in the Night

DAVID ALLEN

I heard about the assassination of John Kennedy on a portable radio in a hut on the Derbyshire Pennines. It was a school camp. I remember how each of us stopped what we were doing – in my case playing table tennis – in stunned silence. Kennedy's death was one of those rare events that not merely blends into the cloth of history, but actually kinks and pierces the fabric as it is being woven. Many are those who can recall the exact circumstances under which they learnt the news.

February 25, 1987 was for me another such kink in the cloth of time, a moment when history – at least astronomical history – was made, and I will carry the memory through life.

I was in the terminal room, the place one goes to hammer away at one of the host of keyboards that commit modern astronomers to slavery at the hands of the omnipotent computer. Spectra were coming up on the terminal screen, wiggly grey lines coursing across a darker grey background; I was trying to finish a bit of analysis before the morning mail came in and I felt obliged to deal with matters administrative. A colleague, Jeremy Walsh, sat down beside me.

'Do you know anything about a supernova in the Large Magellanic Cloud?' he asked.

'No,' I answered casually, my mind still on the spectra.

'Jean-René just rang me from Canada,' Jeremy continued. 'He says there's a report of one.'

I began to take in what Jeremy was saying. The wiggly grey lines grew fainter before me. A supernova in the Magellanic Clouds – a bright, naked-eye supernova, accessible only to southern observatories; the implications raced through my mind.

I remembered the telex machine, which would have last been cleared about 8.30 a.m. There I found a fresh new telex message from the International Astronomical Union: all the details were given – a supernova had indeed been found. Details were beginning to come in from our telescope, too, some 500 km away on Siding Spring Mountain. Unusually, it bore equipment of little

LEX MESSAGE TELEX

SHELTON DUHALDE MCNAUGHT LMC 1987A SUPERNOVA SHELTON
 19871 70224 333// 05354 16916 03045 48710 25315
 BRIGHTENING 0.5 MAGNITUDE IN FIVE HOURS
 GREEN 4FEB24/1500Z
 SENT ON FEB 25 09:32:29 1987

* AAOSYD AA123999
 IPSO AA20663*
 AAOSYD AA123999

SHELTON DUHALDE JONES 1987A LMC SUPERNOVA MCNAUGHT
 19502 70224 05355 02216 91759 25045 14101 24375
 BRIGHTENING ONE MAGNITUDE DAILY
 BLUE NONVARIABLE MAGNITUDE TWELVE OBJECT WITHIN ONE ARCSEC
 THROUGH 70222
 MENZIES SPECTRUM SHOWS MAYBE TYPE ONE
 REF EARLIER MSG MCNAUGHT NOT CODISCOVERER
 MARSDEN 5FEB25/0130Z
 SENT ON FEB 25 15:56:54 1987

* AAOSYD AA123999
 IPSO AA20663*
 AAOSYD AA123999

MESSAGE

TELEX

Figure 1. These two telexes brought news of the discovery of SN 1987A. In the first, Rob McNaught is incorrectly credited with discovery; this error is corrected in the second, in which he draws attention to the precursor star. The strings of 5-figure numbers are not obscure codes, but standard abbreviations used in transmitting astronomical data. For example, the (apparent place) co-ordinates $5^{\text{h}}35^{\text{m}}.4 - 69^{\circ}16'$ can be seen in the first telex.

value for observing supernovæ, so the only observations had been by smaller telescopes, including a photograph by Rob McNaught.

The story of the discovery is now history, and everyone has had a chance to read of Ian Shelton's photograph, of Oscar Duhalde's casual sighting, of Albert Jones's discovery. I won't repeat this tale here. But I do want to stress the role that Rob McNaught played.

In essence, Rob is an amateur astronomer. I say this with respect, for although he is employed to operate the Aston University satellite tracking camera at Siding Spring Observatory, it is for the work he does as an amateur that he is best known. Rob initiated a photographic survey for novæ in the Magellanic Clouds. Every clear night he secures at least one such photo, and during the following day he scans it in a home-made blink comparator for new stellar images. He found his first nova in the Small Magellanic Cloud late in 1986, a few weeks after discovering a naked-eye Galactic nova in Centaurus.

On February 23 Rob gathered two photographs of the Large Magellanic Cloud shortly after sunset. By a rare quirk of fate he was unable to examine the images the next day. Those photographs remain the first taken by anyone to show the supernova, and have been one of the most valuable pieces of information in piecing together its eruption. Anyone looking at it through a telescope then would have seen it perceptibly brighten as they watched. Had Rob examined the photographs he would have been the sole discoverer of SN 1987A, the first naked-eye supernova since the invention of the telescope. Instead, he learnt of it twenty-four hours later, when a phone call from New Zealand alerted him to Albert Jones's discovery.

What impressed me was the marvellously phlegmatic way Rob took all this. He himself wrote 'my disappointment at not having checked my photos . . . was offset by the excitement of seeing a supernova with the naked eye.' Rob photographed the supernova with the satellite camera as soon as he heard of it, measured up the plate and correctly identified the precursor star from photographs taken before the eruption. All this on the night of February 24 while I was sleeping peacefully in my bed at home.

Over the next thirty-six hours the telephones ran hot. Colleagues from around the world called me at work or home to seek details. My good friend Paul Murdin was one, calling from the Royal Greenwich Observatory. 'Lucky', Paul commented. At the

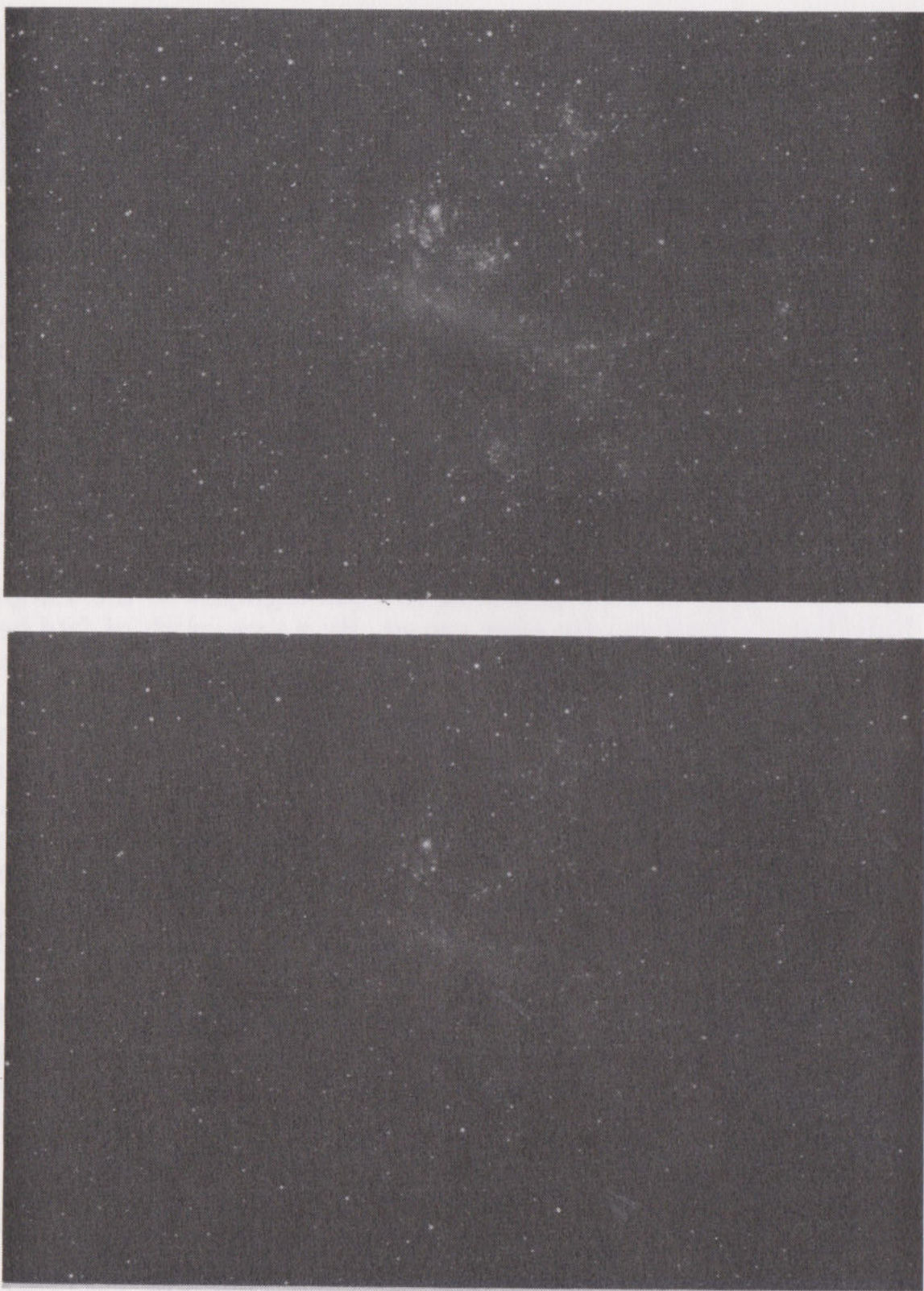


Figure 2. Spot the difference. SN 1987A was recorded for the first time on Rob McNaught's photograph of February 23 (lower). The upper photograph, taken 24 hours earlier, does not show it. Even with this information, it takes a deal of searching to find the supernova, which lies a little below the bright nebula above the brightest part of the 'bar' of the galaxy.

time I believed him, but over the next few days I began to doubt his words.

Suddenly time had been cleft into two epochs, *BS* and *AS*. *BS* (before the supernova) had been busy, as always; but looking back it seems as relaxing as those halcyon days of my youth. Most of the research I was doing *BS* abruptly ceased *AS*. Those wiggly grey spectra being sketched across the computer terminal were truncated part way along. *AS*, only one object existed: SN 1987A.

The next morning Russell Cannon, my Director, called a meeting to discuss the supernova. Word of the meeting spread, and most astronomers within the Sydney area packed into the room. We had to remove all the tables to fit in extra chairs (we could have used smaller chairs, as everyone was on the edge of theirs), and throughout the meeting Russell and I had to take turns at answering phone calls. Apart from bringing everyone up to date with the situation, the meeting had also to decide how to handle the supernova. Should we, for instance, throw all scheduled observers off the telescope and devote all of the time to observing the new star? This seemed pretty harsh on people who had won time on the telescope against stiff opposition. We decided to take one hour per night from all scheduled observers for supernova work, and to do as much rearrangement of the telescope schedule as possible to permit longer spells of observation.

But exactly what measurement should we make? There were no supernova experts on our staff, and though professional astronomers have for many years debated what they would do in the unlikely event of a bright supernova, most of the coffee-table talk paled before the real thing. We were more than glad, therefore, to have had a call from Craig Wheeler at the University of Texas, only minutes before our meeting, with recommendations. Craig is one of the world experts on the analysis of supernovæ. Later he and his collaborator Robert Harkness came over to Australia to give us more help and to describe their own work.

Russell closed the meeting and hurried out to a television interview. The media had caught wind of this story, and over the next few days we had also to face a barrage of press enquiries that exceeded the height of Halleymania. By Sunday, when Russell left on a visit to the UK, I became their target.

Graeme White, of the CSIRO, spent virtually the entire day measuring the first photographs from our telescope. The star Rob McNaught had identified as the precursor had turned out to be

double; Graeme's measurements showed that it was the brighter star that coincided with the supernova. This was the first time that the precursor to a supernova had ever been identified.

The Australian Broadcasting Corporation TV news wanted to follow up on the measurements. They rang me to ask for an interview, in twenty minutes time in my house. When they called, I was re-plumbing our kitchen: I was filthy and I had the water turned off. We had let the kids take over the rest of the house, which therefore looked like a battlefield, and heavy rain prevented an interview in the garden. Viewers that night had no idea what lay behind the simple head-and-shoulders shot!

The pressure continued. Almost daily we had to review the changes the supernova had undergone and the observations made with our telescope and elsewhere in the southern hemisphere, and decide what type of observations to take next. Almost daily we had to deal with the press. I thought that a visit to the telescope would simplify things, but the telephones kept ringing at all hours of the day and night, and a team from *Time* magazine followed me up there. I stood with the reporter from *Time*, watching the twilight fade until the supernova became visible. It was then that I realized this was the first time in recorded history that a star in another galaxy had been visible to the naked eye.

Someone questioned that statement, recalling the supernova in the Andromeda galaxy in 1885, so I found time to read the accounts of that one. They made interesting reading, for at the time the Andromeda galaxy was still thought to be a nebula within our own, and its supernova was mistaken for an ordinary nova, that much paler event that occurs only on the surface of a white dwarf star. Technically the Andromeda supernova became just bright enough for naked-eye vision, but it was never recorded, and would have been hard against the galaxy itself. Subsequently Rob and I have been trying to track down rumours that Polynesian sailors, who used the Magellanic Clouds as navigation aids, handed down oral reference to previous supernova in these galaxies. We'd be pleased to hear from any readers with information.

What complicated planning for SN 1987A was its individuality. From the outset it refused to be a textbook case. Every day we wondered what it was about to do. Some pundits said it would flare up much brighter; others that it was, at 4th magnitude, already at its peak and would soon begin to fade. Yet others

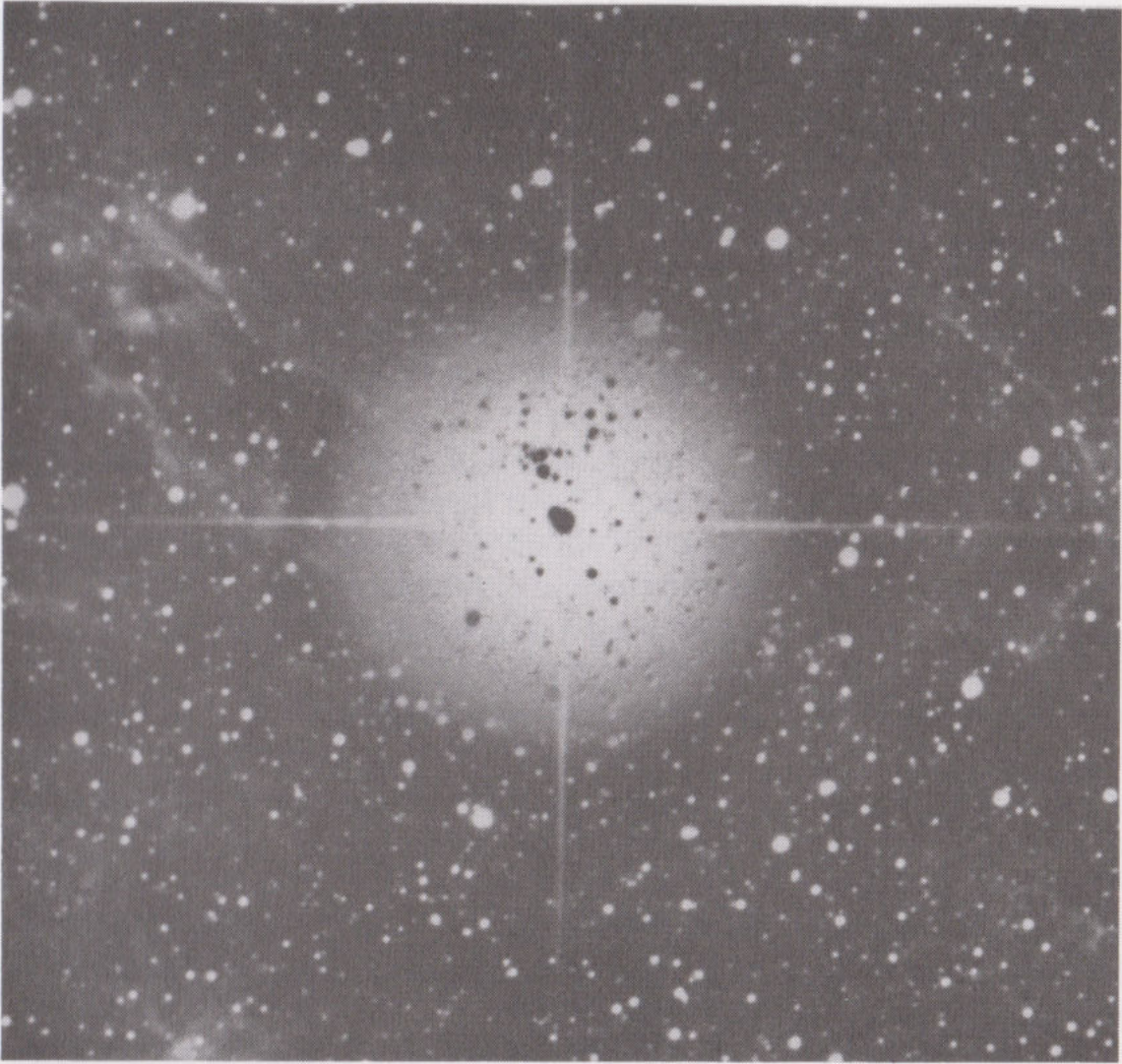


Figure 3. David Malin used positive and negative photographs from BS and AS in this graphic combination. The diffraction spikes from the supernova, generated by the telescope, intersect at the precursor star, whose image is perceptibly oval due to a close companion.

suggested that it would mantle itself in a cloud of dust by about August and become totally extinguished. What SN 1987A chose to do was to brighten steadily to a peak of magnitude 3.0 about May 20, fade rapidly for one month, then fall at a steady rate of about one magnitude every 175 days. I live about one mile south of my office, and on clear May evenings my walk home was romantically lit by the supernova, glowing orange high before me, and easily visible against even the bright skies of Sydney.

Between the major southern observatories in Australia, South Africa and Chile, an impressive archive of data has been gathered.

It was recognized that for this event, almost certainly unique in the lifetimes of any of today's astronomers or telescopes, the gathering of data was of paramount importance. Detailed analysis of those measurements may take decades. Obviously there is great interest in rapid interpretation; indeed, astronomers have been falling over themselves to utter initial pronouncements, though few will stand the test of time. The description that follows necessarily incorporates some of these preliminary thoughts, so if aspects of it seem dated by the time you read this, please be forgiving.

The Magellanic Clouds, being rather youthful galaxies, are well populated by young, hot stars. In our Galaxy, most such stars have already left the scene. Many of those stars are so massive that their interiors are under extreme pressure, and run very hot indeed. As a result, they romp through a host of nuclear reactions so that at an age of only about one million years a star can have developed an onion-like structure. In the outermost shell hydrogen atoms fuse to helium, as in the Sun. In the next shell inward helium fuses to carbon and oxygen. Deeper in, neon is formed, then silicon and so on up the chain as far as the iron group (iron, cobalt, nickel). There the sequence stops. All the way up to the iron group energy is given out by the fusion, the energy that makes the star shine. Beyond iron, energy must be put in, a situation that is precluded in those conditions by thermodynamics.

A huge quantity of iron accumulates at the centre of such a star. Eventually, however, the inescapable force of gravity takes hold. Devoid of any further source of energy to give it buoyancy, the iron core collapses under its own weight. It does so extraordinarily quickly in a different type of nuclear reaction. Only a few seconds are needed for every proton and electron in the core to combine to form neutrons: it is iron no more. A neutron star is born deep inside an otherwise conventional star.

The star finds the birth process traumatic. Its first birth pains are caused by a wave of neutrinos that race outwards at the speed of light. Neutrinos are very inert elementary particles, much tinier than the constituents of atoms, and virtually all pass through the star to escape into space. The number of neutrinos liberated is truly astronomical. SN 1987A lies 170,000 light-years from us, but even after fanning out over that extraordinary distance, about one million million of its neutrinos passed through every square centimetre of the Earth, including those patches occupied by you

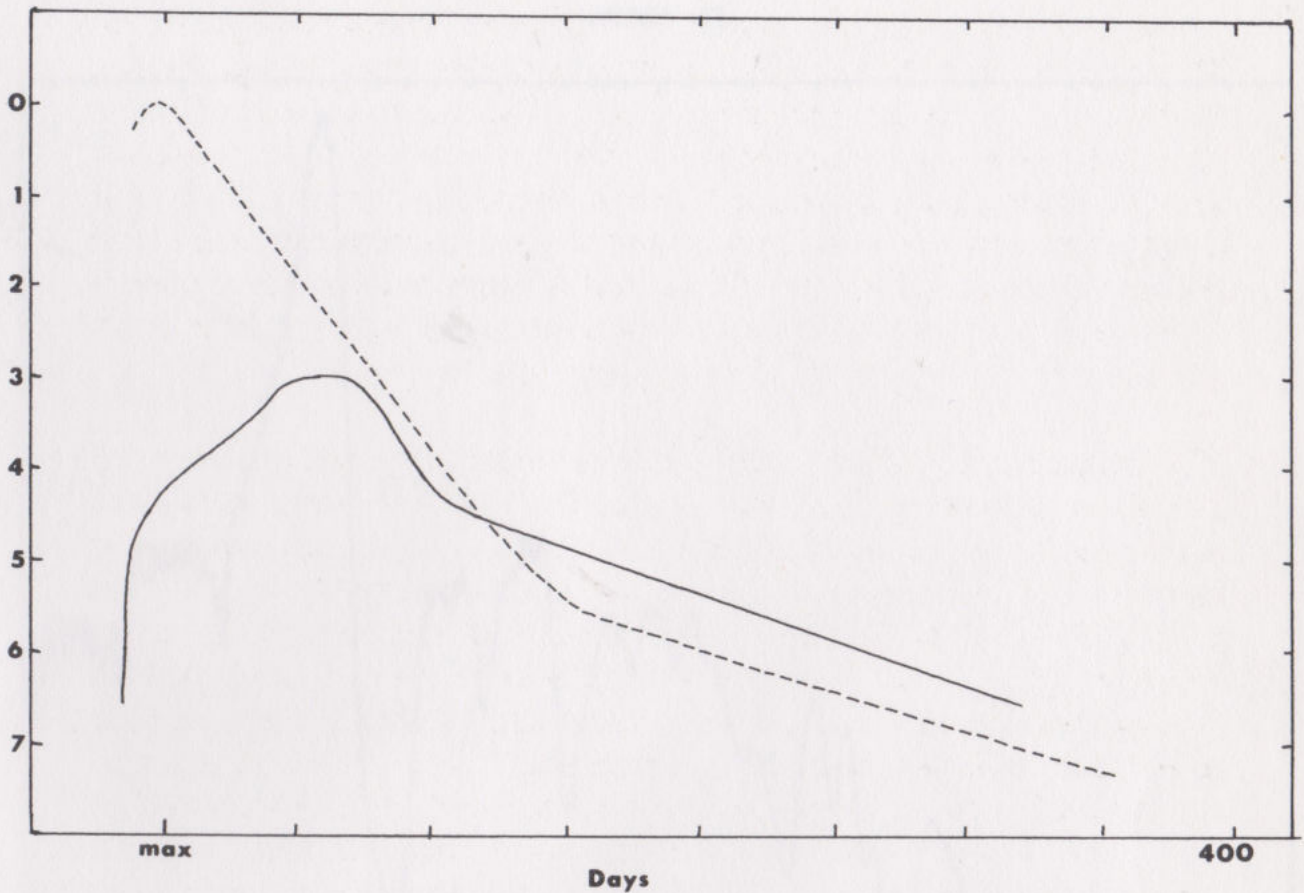


Figure 4. The light curve of SN 1987A is a plot of its brightness in stellar magnitudes at various dates, and shows the peak in mid-late May. The broken line shows the typical behaviour of normal supernovæ of this type. In both cases, the long, straight decline is caused by the decay of radioactive cobalt.

and me. A few – a scant couple of dozen – were captured by special neutrino detectors as they emerged unscathed from traversing the Earth. The first ever received from a supernova, they bore elegant testimony to our understanding of much of physics.

A more devastating birth pang befalls the precursor star. Like ripples from a stone tossed in water, a mighty splash emanates from the collapsed core. A shock wave, travelling at some tens of thousands of kilometres every second, races outwards. Some of the energy of the shock wave goes into nuclear fusion of the outer layers, so that another considerable mass of iron-group elements is produced. This time conditions allow the formation of heavier elements, too. All the gold, silver, lead, uranium and the like found here on Earth is believed to have been generated in

SN 1987A

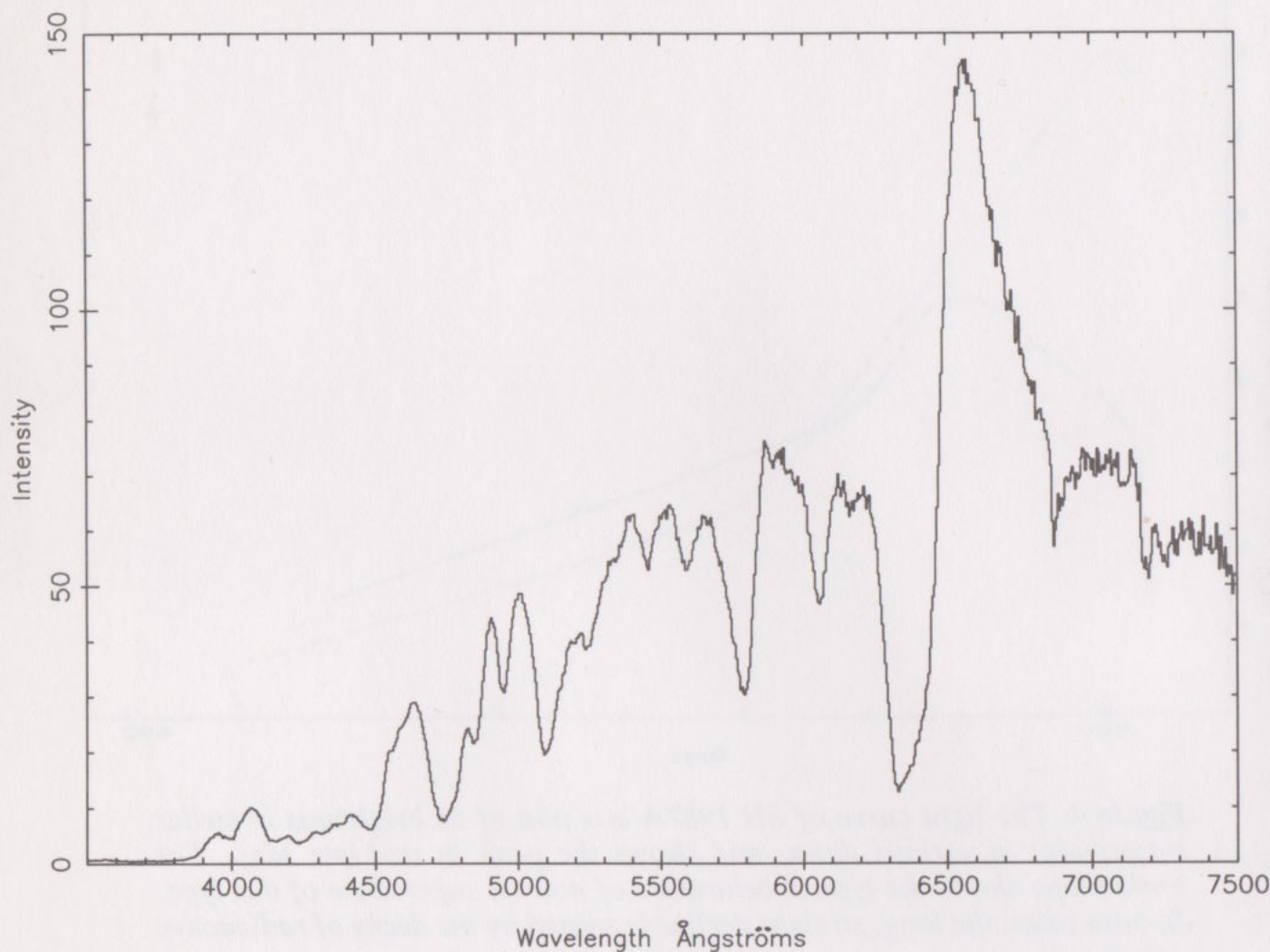
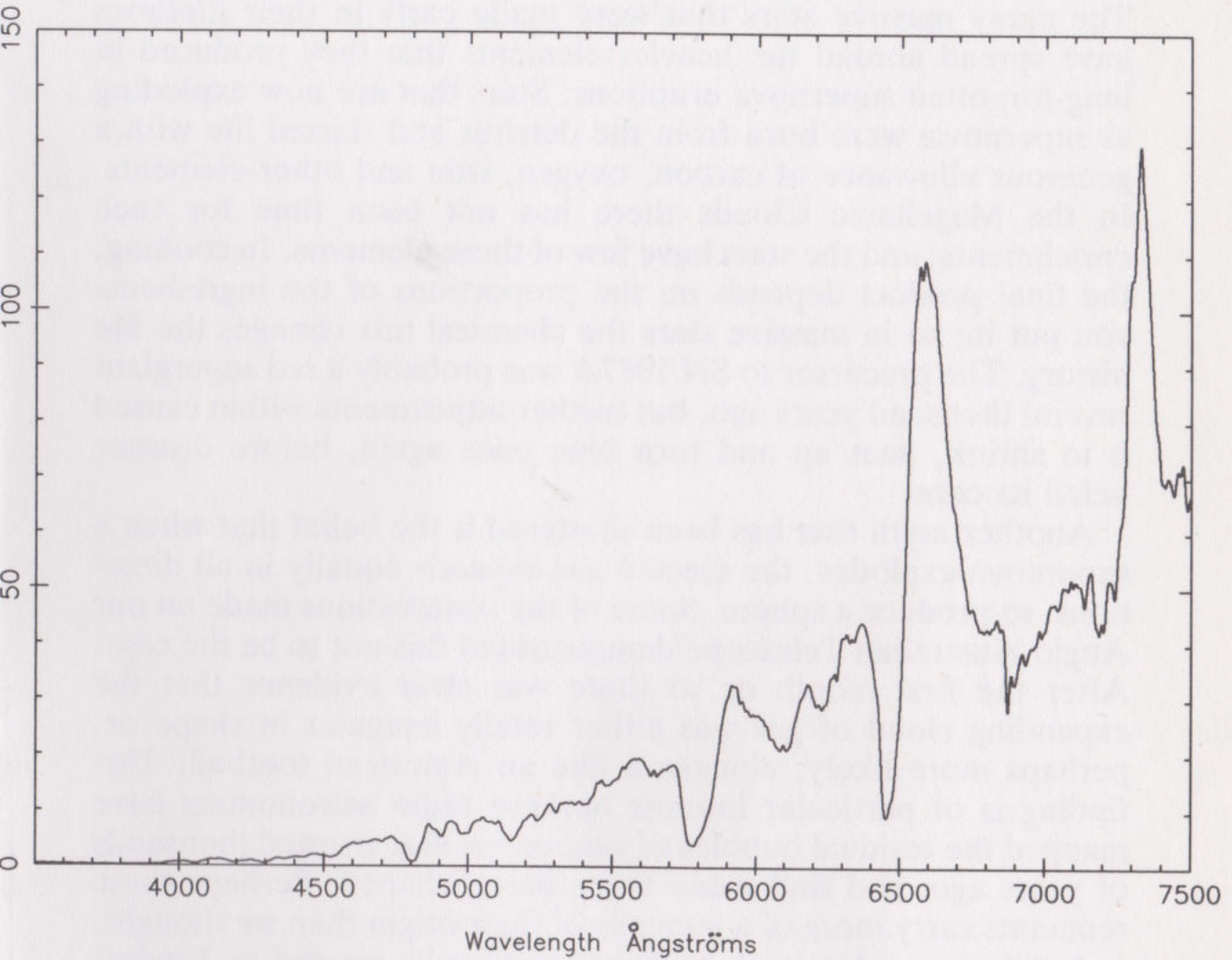


Figure 5. These uninteresting wavy lines are the spectra that excite professionals so. Note how much SN 1987A changed between ages of two weeks (above) and five months (opposite). Both spectra are from the archive of the Anglo-Australian Telescope.

supernovæ like 1987A that erupted when our Galaxy was young, and before our planet formed. The remaining energy of the shock wave is spent in snow-ploughing the outer layers away at the same enormous velocity. SN 1987A was a result both of the star suddenly being inflated, and of the extra energy liberated by radioactive processes triggered by the shock. The former accounted for the initial brightening, and the latter for the subsequent peak in mid-May.

According to the perceived wisdom *BS*, a massive star will attain

SN 1987A



the core catastrophe at a time when its outer layers have been inflated as a result of the processes occurring in the various onion layers. The star is then a red supergiant – like Antares or Betelgeux – and the expanding shock wave is traversing relatively tenuous outer layers. But the precursor to SN 1987A was not a red star at all, and we now recognize that as the reason for the supernova's unique initial behaviour. It was a blue supergiant, with denser outer layers that stifled the shock wave and thus dimmed the initial brightening. A textbook supernova in the Large Magellanic Cloud would have become perhaps ten times as bright, rivalling nearby Canopus in apparent brightness.

Why was SN 1987A a blue star when it exploded? This question exercised the theorists over the first few months, and several independently came up with what now appears to be the accepted

answer. Most galaxies are older than the Large Magellanic Cloud. The many massive stars that were made early in their lifetimes have spread abroad the heavier elements that they produced in long-forgotten supernova eruptions. Stars that are now exploding as supernovæ were born from the detritus and started life with a generous allowance of carbon, oxygen, iron and other elements. In the Magellanic Clouds there has not been time for such enrichments, and the stars have few of these elements. In cooking, the final product depends on the proportions of the ingredients you put in; so in massive stars the chemical mix changes the life history. The precursor to SN 1987A was probably a red supergiant several thousand years ago, but further adjustments within caused it to shrink, heat up and turn blue once again, before disaster befell its core.

Another myth that has been shattered is the belief that when a supernova explodes, the ejected gas expands equally in all directions, to produce a sphere. Some of the observations made on our Anglo-Australian Telescope demonstrated this not to be the case. After the first month or so there was clear evidence that the expanding cloud of gas was either totally irregular in shape or, perhaps more likely, elongated like an American football. This finding is of particular interest because radio astronomers have mapped the residual bubbles of supernovæ that erupted thousands of years ago, and find many to be barrel-shaped. Perhaps these remnants carry more of a memory of their origin than we thought.

Another popular myth is being continually eroded as I write. The neutron star that should have formed at the heart of the supernova is expected to have turned into a pulsar, with jets of radiation spinning hundreds of times per second like a speeded-up lighthouse. The theory of very young pulsars suggests that they should liberate a great deal of energy, and some astronomers have argued that a pulsar is the major source of energy after the first few months. However, the rate at which SN 1987A is fading so exactly matches that predicted for the radioactive decay of cobalt to iron that there can be no very bright pulsar hiding within. The cobalt was formed by the radioactive decay of nickel, which was produced as the shock wave traversed the star. Eventually the expanding gas will clear enough for us to see any pulsar inside.

SN 1987A remained visible to the naked eye for eight months. Only the foolhardy attempt predictions, so suffice to say that the glowing ball of gas will still be observable for a few years yet,

before it blends into the dense star field around it. The eventual remnant will be studied for some millenia. SN 1987A will not be forgotten in my lifetime. Fortunately, however, the object is changing ever more slowly. No longer is it necessary to make nightly observations, and for many purposes only a few measurements per year now suffice. I have even begun to pick up those wiggly grey lines from *BS*.

Yes, 1987 was a phrenetic but an intoxicating year to be a professional astronomer in the southern hemisphere.

Astronomy with Gamma-Rays

A. W. WOLFENDALE

1. Introduction

In 1980 I wrote an article for the *Yearbook of Astronomy* entitled 'Gamma-Ray Astronomy'. In it I pointed out that this was the final window of the electromagnetic spectrum to be opened up and that here we had an exciting new branch of astronomy in the making. The present article represents an up-date of the subject and endeavours to answer the questions: *What has happened since 1980?* and *Where do we go from here?*

First of all let us re-cap on the sorts of processes producing γ -rays, remembering that γ -rays are beyond X-rays in the spectrum, with quantum energies extending upwards of, conventionally, 511 kilovolts. Figure 1 shows the main production processes.

We see immediately some of the exotic mechanisms at work and this is the main virtue of γ -ray studies. This is not the area of conventional optical astronomy where the atmospheres of stars at perhaps 6000K are producing the radiation – rather we are dealing with plasmas at 10^{10} K and above, with exotic matter – anti-matter annihilation, with radioactive nuclei flung out of exploding stars or with the results of collisions of the enigmatic cosmic-ray particles.

Allied with the exciting production mechanisms we have the other main feature of γ -rays – their great penetration. As every optical astronomer knows, we can only see about a quarter of the way to the Galactic Centre because of absorption of starlight by the dust in the interstellar medium (ISM). With γ -rays (and indeed with X-rays, too, above about 2 kilovolts), however, there is essentially complete penetration (unless, and most rarely, a star gets in the way).

All this is the good news. The bad news is that so far, at least, the number of photons detected has been incredibly small. At energies above several hundred million volts, the region of most interest to the author, only a few hundred thousand photons have been recorded in the two major satellite experiments. Such a number is laughably small to the optical astronomer who would collect about ten thousand times this number in a one second exposure with just a small amateur telescope. There is worse to

come, however, in that the γ -ray images are incredibly blurred, so far. No 'seconds of arc resolution' here – a fuzziness to the extent of one degree is commonplace. Nevertheless some exciting results have appeared already and an attempt will be made to give their flavour in this brief article.

2. Strange happenings in the Galactic Centre

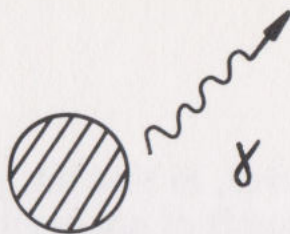
Centres of galaxies are places where dramatic phenomena have a habit of happening, and the centre of our own Galaxy is no exception. Millimetre astronomers tell us that there are extraordinarily massive clouds of gas there, some of it apparently being puffed out rather like a smoke ring. X-ray sources of great power are also present. The most exciting observations, however, are probably those in the γ -ray field, specifically the observation of the characteristic 511 keV line due to the annihilation of positive and negative electrons (see Figure 1). The whole question of the existence of anti-matter (positive electrons in this case) is an intriguing one, and there are great arguments for the Universe as a whole of whether or not there is symmetry with equal quantities of matter and anti-matter. One thing that is clear is that the amount of anti-matter in the Solar System, the Galaxy and indeed the local Supercluster of galaxies is small, but beyond that it is anyone's guess. But to return to the Galactic Centre, somehow anti-matter (e^+) is being produced at a great rate and the question is: *How?*

Inevitably, when in doubt, postulate a black hole and it does seem that there is a good chance that such an object is responsible here (some astrophysicists believe that many galaxies have black holes at their centres). The idea is that the black hole, of perhaps a million solar masses, accretes local gas to form a disk on the surface of which there are hot spots which boil off $e^+ e^-$ pairs. The e^+ then annihilate in the plasma near the hole to produce pairs of 511 keV γ -rays.

Figure 2 shows the energy spectrum of γ -rays from the general direction of the Galactic Centre; the 511 keV line stands out very clearly. The remaining nearby X-rays are presumably generated by the hot plasma which inhabits the GC region.

One potential problem, or excitement, concerns the apparent variability of the emission. Since its first detection in 1970 the intensity seems to have varied by a factor of 4 or so and some authors claim that this is because the black hole has irregular meal

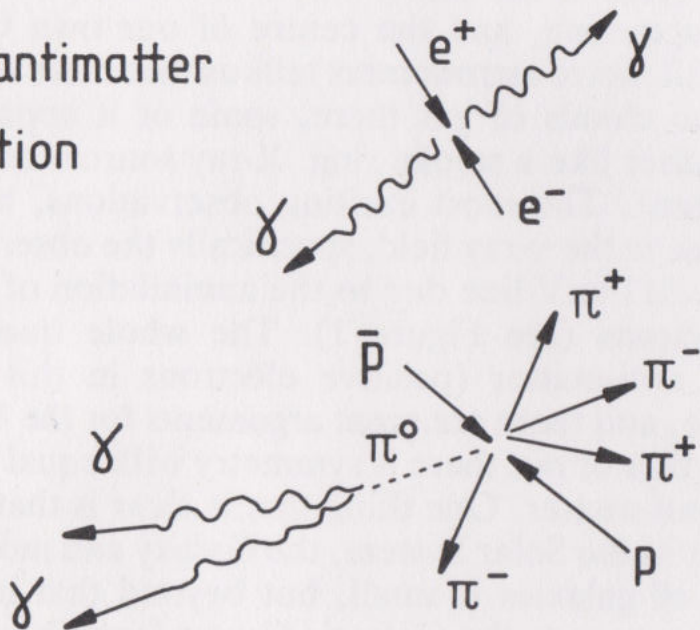
Hot plasma



Radioactivity



Matter - antimatter
annihilation



Energetic particle
collisions

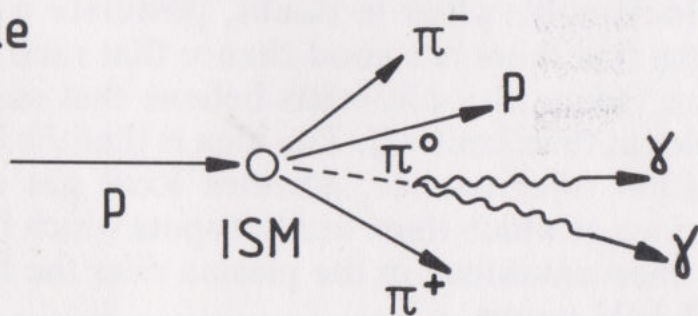


Figure 1. The major processes by which cosmic γ -rays are generated

A^* represents a radioactive nucleus, such as one born in a supernova explosion. e^+ and \bar{p} (positron and anti-proton) are the anti-matter partners of electrons and protons.

π^+ , π^- and π^0 are pions, particles of mass about 270 times the mass of the electron. They represent the nuclear glue holding nuclei together. The neutral pion (π^0) has a very short lifetime ($\approx 10^{-16}$ seconds) and decays into two γ -rays.

'ISM' represents a nucleus (usually hydrogen) of the interstellar medium.

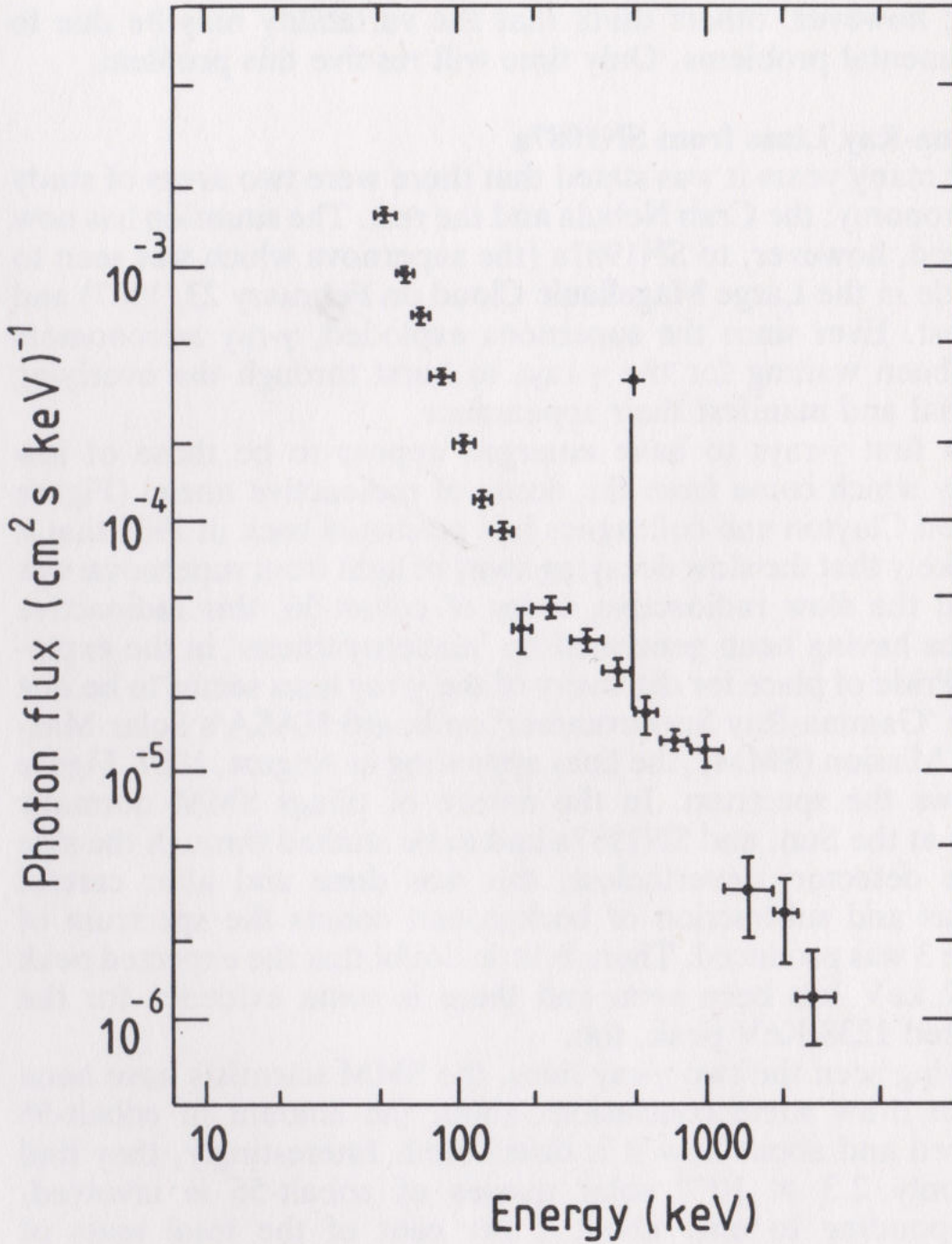


Figure 2. The γ -ray spectrum from the region of the Galactic Centre observed with the gamma-ray spectrometer on the HEAO-3 satellite. The γ -rays resulting from the annihilation of electrons and positrons – at 511 keV – are clearly visible.

times; however, others think that the variability may be due to instrumental problems. Only time will resolve this problem.

Gamma-Ray Lines from SN1987a

For many years it was stated that there were two areas of study in astronomy: the Crab Nebula and the rest. The situation has now changed, however, to SN1987a (the supernova which was seen to explode in the Large Magellanic Cloud on February 23, 1987) and the rest. Ever since the supernova exploded, γ -ray astronomers have been waiting for the γ -rays to burst through the overlying material and manifest their appearance.

The first γ -rays to have emerged appear to be those of low energy which come from the decay of radioactive nuclei (Figure 1). Don Clayton and colleagues had predicted back in 1969 that it was likely that the slow decaying away of light from supernovæ was due to the slow radioactive decay of cobalt-56, this radioactive nucleus having been generated by 'nucleosynthesis' in the explosion. Pride of place for discovery of the γ -ray lines seems to be due to the 'Gamma-Ray Spectrometer' on board NASA's Solar Maximum Mission (SMM), the lines appearing in August, 1987. Figure 3 shows the spectrum. In the nature of things SMM normally points at the Sun, and SN1987a had to be studied through the side of the detector; nevertheless, this was done and after careful analysis and subtraction of background counts the spectrum of Figure 3 was produced. There is little doubt that the expected peak at 847 keV has been seen and there is some evidence for the expected 1238 KeV peak, too.

Having seen the two γ -ray lines, the SMM scientists have been able to draw some conclusions about the amount of cobalt-56 involved and about how it is distributed. Interestingly, they find that only 2.3×10^{-4} solar masses of cobalt-56 is involved, corresponding to only about 1 per cent of the total mass of cobalt-56 thought to be present and required by the light curve. This fact, taken with the relative strengths of the lines in Figure 3, leads them to postulate that the envelope of the supernova is non-uniform so that the γ -rays can escape from only a small fraction of the radioactive material. It will be interesting to see how the lines develop as time goes on and the supernoval ejecta disperse.

4. Gamma-Ray Energies in the 100s of MeV Region

In my 1980 article I pointed out how γ -rays in this energy

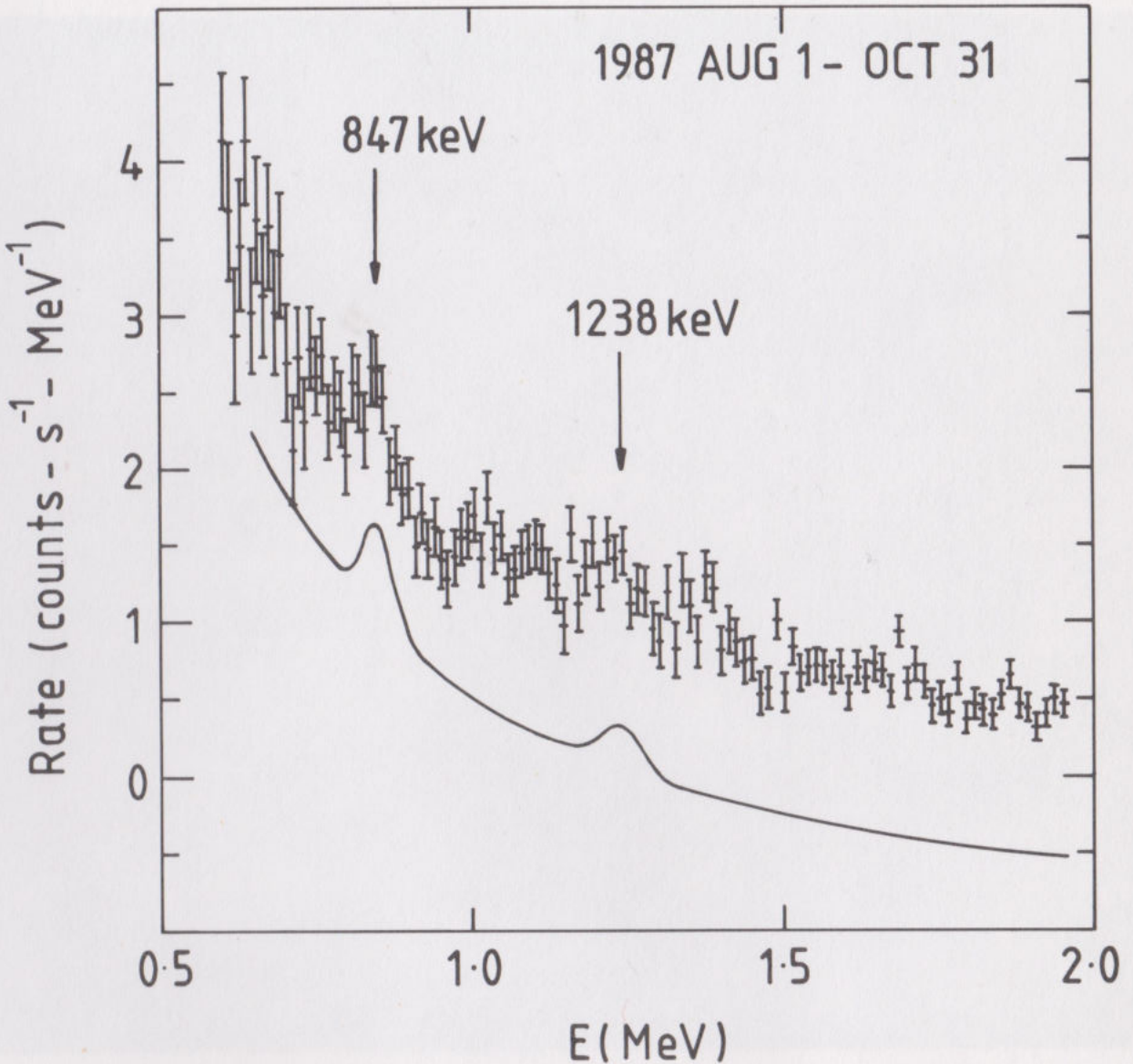


Figure 3. The first results on γ -ray lines from the supernova SN1987a. The data came from the gamma-ray spectrometer on board NASA's Solar Maximum Mission Satellite (SMM).

The smooth curve under the experimental points shows what would be expected if the lines from cobalt-56 were detected with the resolution of the instrument.

Some of the peaks in the experimental data coincide with the predicted peaks – the coincidence at 847 keV being particularly significant. It seems likely that some, at least, of the other peaks observed experimentally are γ -ray lines – presumably of non-cosmic origin.

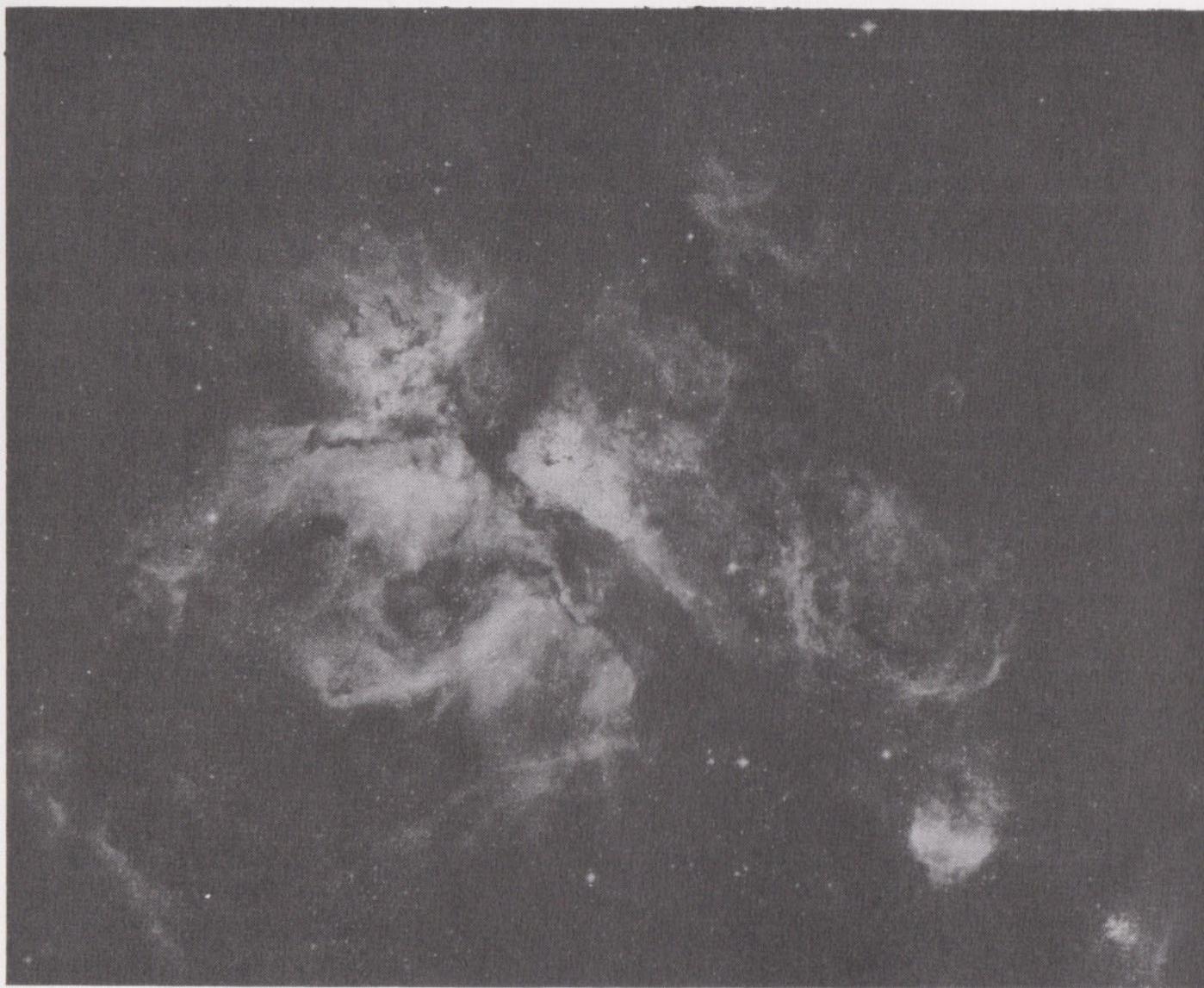


Figure 4. The Eta Carinae Nebula. Most of the energy for this nebula is coming from a star now shrouded by gas and dust. Early in the last century the star – then visible – began to brighten remarkably so that by the 1840s it was emitting energy at six million times the rate of the Sun. The dust now absorbs much of the visible light but transforms it into infra-red radiation: Eta-Carinae is now the brightest infra-red star in the sky. We think that the excess γ -ray flux coming from this direction is due to cosmic-ray particles accelerated in the vicinity of the star and interacting with the gas there. (Reproduced by courtesy of David Malin, Cambridge University Press)

bracket were throwing light on the thorny question of 'the origin of cosmic rays'. Cosmic rays are atomic particles, mainly hydrogen nuclei, protons, which seem to pervade the whole of the Galaxy and perhaps beyond, and have been measured at Earth with energies as high as 10^{20} eV (see my article 'Cosmic Rays of the Highest Energies; in the *1981 Yearbook*).

So far the γ -rays detected can only tell us about cosmic-ray particles below about 10^{10} eV, but even this information is useful because most of the particles are indeed down here in energy. Although there is still some argument about the details it does look as though our earlier contention that most cosmic rays are produced in our own Galaxy is correct. Those who believe that cosmic rays fill the whole of the Universe at the same level everywhere are becoming an endangered species.

The principle of the γ -ray method can be appreciated by reference to Figure 1 (energetic particle collisions). One looks in a direction in the sky where you think you know how much gas there is and, having measured the γ -ray flux (with satellite-borne detectors), the average intensity of the cosmic-ray particles in that direction can be inferred. Emphasis now is placed on observations of specific giant molecular clouds containing likely energetic stars, supernova remnants and pulsars. γ -ray excesses, strongly suggesting the production of cosmic-ray particles, have been seen from all these objects. Figure 4 shows one such likely 'source' – Eta Carinae – which comprises a star which flared to a luminosity of over six million times the luminosity of the Sun in the last century and is immersed in a dense cloud of gas which is acting as the target for the cosmic-ray particles.

The above is not to imply that we know all about cosmic-ray origin. Far from it, the manner in which the particles are accelerated is still far from clear, although some form of shock acceleration seems likely, in some situations at least.

5. The Mass of Gas in the Galaxy

One of the by-products of gamma-ray studies has been an improvement in knowledge of the amount of gas in the Galaxy. Twenty years ago it was thought that the gas comprising the interstellar medium (ISM) was primarily atomic hydrogen and its distribution was mapped using the 21-cm line – the 'song of hydrogen'. However, more recently there has come the realization that in the dense clouds of dust in the ISM, which are such a

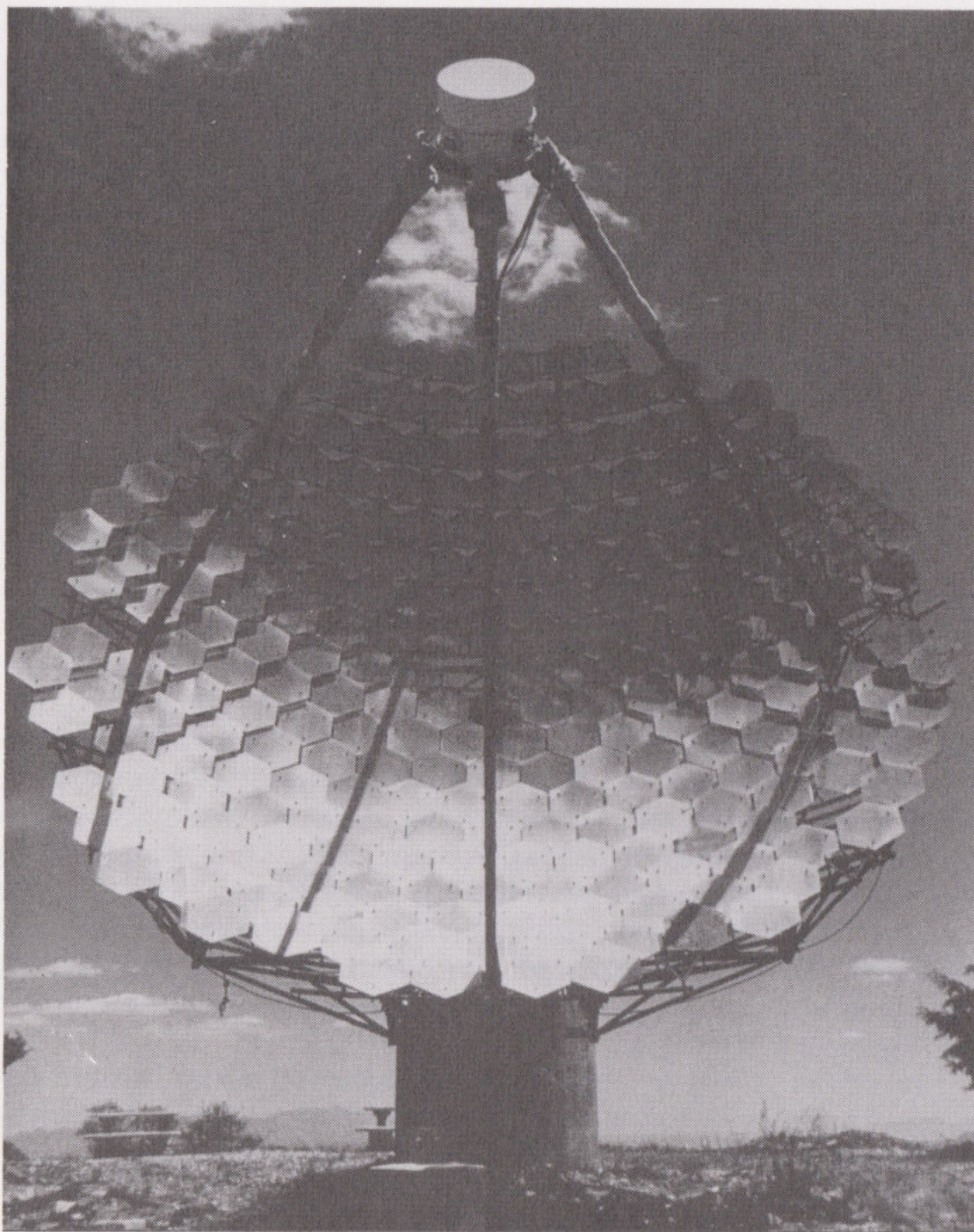


Figure 5. The Whipple γ -Ray Telescope. The 10-metre optical Čerenkov γ -ray telescope at Mt Hopkins, Arizona. The telescope is at an altitude of 2.3 km above sea level. (Photo reproduced by courtesy of Dr R. C. Lamb)

prominent feature of the visible sky, which blot out big regions at optical wavelengths, there are considerable quantities of molecular hydrogen. This gas has no line in any easily accessible wavelength region and its presence has usually to be inferred from observations of other molecules which can be detected. The molecule most commonly used is carbon monoxide, and the hypothesis is that this molecule emits radiation after it has been 'excited' by a collision with one of the much more numerous hydrogen molecules. Inevitably the conversion from the signal in carbon monoxide to the density of molecular hydrogen is a difficult one and there have been heated arguments.

My own group believes that there is much less molecular hydrogen than had been previously thought, but this view has proved to be unpopular. Inevitably those who claimed to have found considerable quantities of hitherto unknown gas are not happy about being told that there isn't so much after all. Our method has been to use the mechanism indicated in Figure 1 ('energetic particle collisions') and choose regions where we think that we know what the intensity of cosmic rays is from other arguments, use the measured γ -ray intensity and go on to derive the mass of gas along the line of sight. Such a method is very useful for local gas clouds such as those in Orion, Taurus and Perseus. When applying the method to the Galaxy as a whole we find that there is less mass in molecular form than in the common atomic form (atomic hydrogen) in the Inner Galaxy. Time will tell whether we have got it right.

6. Gamma-rays of the highest energies

The method of detecting γ -rays of very high energy ($10^{11} - 10^{12}$ eV – i.e. nearly one million times that available from radioactive materials) is now becoming well known. One searches for the so-called optical Čerenkov radiation emitted by electrons produced by the primary γ -rays in the upper levels of the atmosphere, these electrons being characterized by their speeds being greater than that of light in air (but not greater than the speed of light in a vacuum, of course). Measurements are limited to clear moonless nights, just as in optical astronomy, and it has taken a number of years to accumulate sufficient data but nevertheless there has been progress.

It has been found that X-ray binary systems are emitting γ -rays at these very high energies, four such sources having been

observed by at least two independent groups of astronomers: Cygnus X-3, Hercules X-1, Vela X-1 and 4U 0115+63. What seems to be happening is that a neutron star is accreting matter from its binary companion and this forms a disk around the star. It seems likely that a beam of particles is accelerated by the neutron star and impinges on the disk, thereby generating the γ -rays but the details are very obscure. Further problems arise with the fact that the emission of the very high energy γ -rays is sporadic and the result is an experimentalists' nightmare – sporadic emission at low intensity so that one is often unsure as to whether a detection is genuine or not. Nevertheless, the sources quoted do appear to represent sound detections.

Concerning Cygnus X-3, an object some 40,000 light-years away, its output is quite enormous and there have been reports of observations at energies as high as 10^{15} eV. It has been calculated that just one 'Cygnus X-3' present in the Galaxy is sufficient to account for the whole cosmic-ray particle energy budget at any one time. It is hardly surprising that the emission is sporadic – it would be hard to keep up such a great rate of emission of energy for any length of time.

Figure 5 shows the 10-metre optical reflector at the Whipple Observatory in the Santa Rita mountains in southern Arizona. Much of the pioneering work was carried out using this telescope although there are many other instruments either working now or under construction.

7. The Future

As usual, bigger and better detectors are on the way. Satellite-borne detectors of improved design should be launched soon by a USSR/French group and by the USA. Meanwhile progress in the related fields of radio astronomy leading to improved estimates of gas densities will continue. At the higher energies, as already mentioned, improved Čerenkov detectors are under construction and at the highest energies a variety of particle detectors should clinch detection of 10^{15} eV γ -rays. The advent of SN1987a has led to a great upsurge of activity in the southern hemisphere where feverish activity is taking place in efforts to have detectors ready to detect the high energy γ -rays when they break through – let us hope that these γ -rays appear at measurable intensity levels just as the γ -rays lines have already done.

Cameras for Infra-red Astronomy

IAN S. McLEAN

It is barely ten years since the UK Infra-red Telescope on the 14,000-ft summit of Mauna Kea in Hawaii went into operation. At 3.8 m (or 150 ins) UKIRT was and still is the largest single-mirror telescope in the world dedicated full-time to the science of infra-red astronomy. Modelled on the 1.5-m prototype in Tenerife which was developed by a team from the Imperial College of Science and Technology led by Professor James Ring in the early 1970s, UKIRT was one of the first of the large 'thin' mirrors. The mirror was made at Grubb-Parsons in England under the supervision of the late David Brown and, although initially regarded as merely a flux collector, the final specification for the figure of the primary mirror called for diffraction-limited performance at a wavelength of 10 microns – where 1 micron is one millionth of a metre; the eye is not sensitive to wavelengths longer than about 0.7 micron. Tests showed that the final figure was probably even better than this and images no worse than 0.8" at 2 microns might be possible.

Since that time, UK involvement in long-wavelength astronomy has grown immensely, and the subject itself has blossomed into a key régime in modern astrophysics because it is the best wavelength domain in which to study such fundamental processes as star formation and the primeval development of galaxies. Some highlights of the past decade include the inauguration of UKIRT in 1979, the launch of the Infra-red Astronomical Satellite (IRAS) in 1983 and the opening of the James Clerk Maxwell Millimetre Wave Telescope in 1987. But it is the foresight and the early success with the UKIRT thin mirror which has paid-off handsomely in the past year or so, as a new chapter in the development of infra-red astronomy has transpired.

For many years the greatest of all frustrations felt by the growing community of infra-red astronomers seeking information at these invisible wavelengths was the complete lack of imaging detectors – no one had perfected an easy way to 'picture' the infra-red sky. During the 70s and early 80s, advanced photo-

graphic methods such as those employed at the UK Schmidt Telescope in Australia, complex photon-counting imaging systems such as the one developed at University College London by Professor Alec Boksenberg and colleagues, and of course microchip semiconductor imaging devices – in particular the now famous CCD, all contributed to important strides in optical astronomy. At infra-red wavelengths, only ‘single’ detectors (photocells) or a small number of such detectors were available, making infra-red imaging a painstaking, ‘point-by-point’ mapping process involving thousands of tiny (arcsecond) movements of the entire telescope – not at all like optical imaging! Therefore, not only was single-detector map-making tedious and prone to errors, it was simply impractical to achieve ‘fine detail’ in the resulting picture construction. What was needed was an imaging device analogous to the ubiquitous optical CCD.

As part of a re-organization of resources at the Royal Observatory Edinburgh by Professor Malcolm S. Longair, Astronomer Royal for Scotland, plans were laid as early as 1980 to develop the necessary familiarity with solid-state CCD-type imagers, and then to actively pursue infra-red detector manufacturers. It was well known that the technology, although very difficult, did exist to permit the construction of the infra-red equivalent of a CCD, but the strategic importance of infra-red imaging devices meant that infra-red CCD chips were either classified or of a totally inappropriate specification for low-light-level astronomical applications; most military applications required instant ‘TV-type’ response.

It took two years to research and lobby the primary manufacturing concerns and to develop the support technology, and then a further two years to establish a detailed specification on behalf of the UK astronomy community, agree contractual terms and secure funding and other facilities. In June 1984 an Infra-red Array Project Team was formed at ROE to establish a foundation for infra-red array detector development and to construct the first ‘common-user’ infra-red camera system for a national facility: The team of ten was composed of scientists and professional engineers to cover a wide range of disciplines including optics, mechanics, cryogenics, electronics, computers and software. Modern astronomy is much like that. More and more, the new instruments are being engineered to exacting standards and they inevitably involve computer-control and the use of sophisticated software. Observing

sequences can be pre-programmed, and the results can be appreciated almost immediately using computer display screens at the telescope.

For the new camera a state-of-the-art array with almost 4000 picture elements (pixels) was commissioned from SBRC (Goleta, Ca.) – four times as many as any previous candidate astronomical arrays and, thanks to the UKIRT/ROE programme, commercially available.

The new infra-red camera system, called IRCAM, was completed and delivered to UKIRT virtually on schedule in September 1986. After an extensive period of trials, during which the detector array was up-graded twice with even better models, 'Service Observations' were offered to UK and Dutch astronomers and finally, visiting astronomers were encouraged to 'try-out' the system. The camera became a generally available, common-user instrument with effect from September 1, 1987. When 'first light' was obtained on the 3.8 m UKIRT on Mauna Kea on October 23, 1986 during a few hours of daylight or 'morning observing' – yes, an infra-red camera can work in daylight as well as darkness – the reaction of the IRCAM team was more a 'satisfied sigh' than a 'jump-for-joy – we knew it would work! What we did not know was just how well it would work!

What constitutes an infra-red camera? Well, certainly the heart of the camera is the infra-red detector array, but as we shall see, IRCAM is a complex instrument requiring careful optical, mechanical and electronic design.

The detector is not actually a CCD; it consists instead of an array of 'photodiodes' made from a material called *Indium Antimonide* which is a semiconductor – like silicon but sensitive to infra-red radiation. The array of photodiodes converts at least 60 per cent of the incident infra-red radiation into electrical charge and stores it. Each photodiode is cleverly bonded to an array of silicon transistors to effect a 'direct readout' of the stored charge. Since saturation of any given element of the device merely corresponds to a fully discharged photodiode, the array remains light-sensitive – but integration ceases, and the saturated pixel does not spread or 'bleed' like a CCD. IRCAM is sensitive from a wavelength of 1.0 micron to a wavelength of 5.0 microns. This region is known as the 'near' infra-red and it is physically important because at these wavelengths one can penetrate thick clouds of interstellar material – which behave like a smoke screen

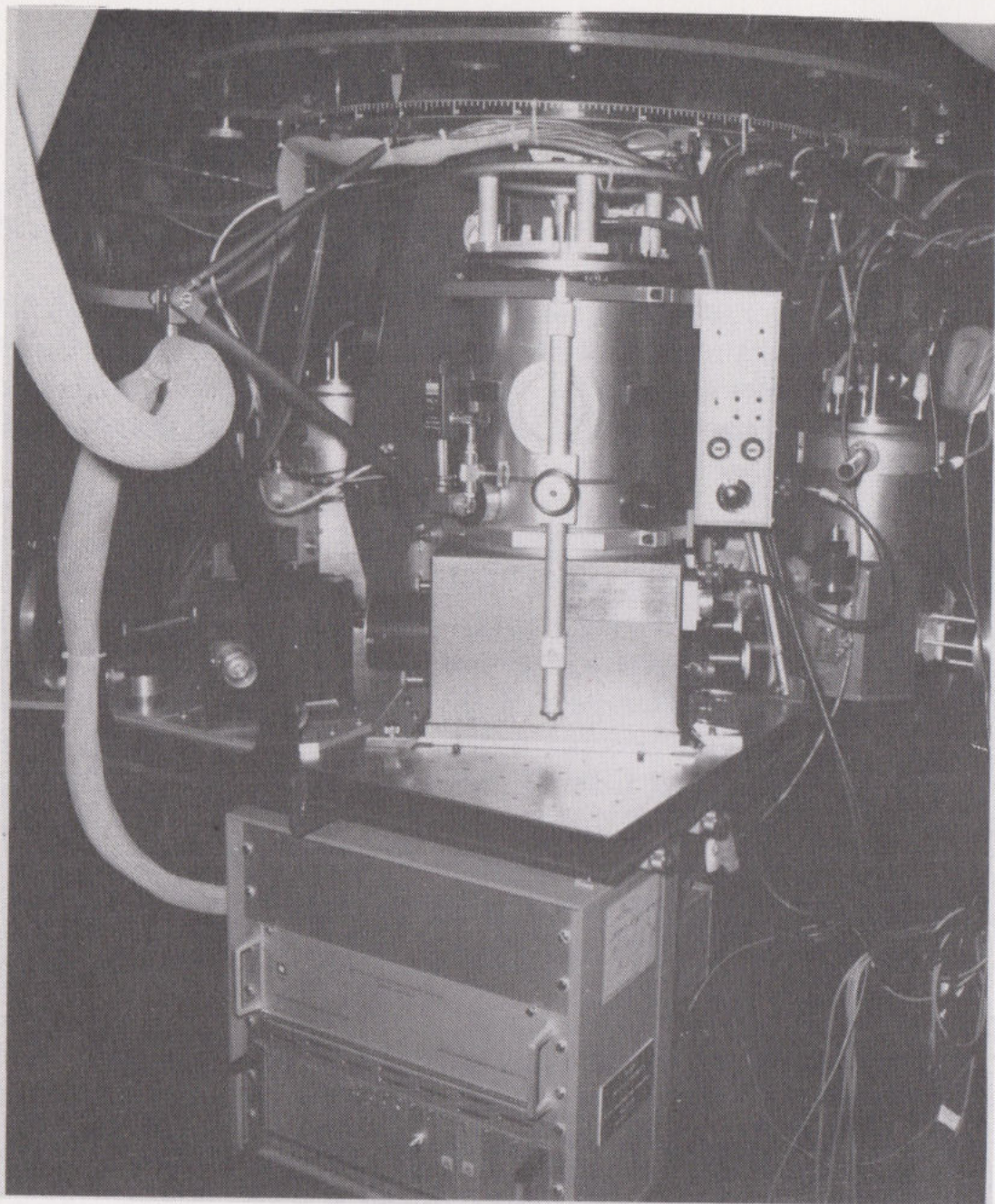


Figure 1. IRCAM, the cryogenic infra-red camera system on the 3.8 m United Kingdom Infra-red Telescope on Mauna Kea, Hawaii. The lower section is a vacuum chamber containing cold filters, lenses and, of course, the infra-red detector. In the cylinder above is sufficient liquid nitrogen to keep the camera cold for over twenty-four hours, and enough liquid helium to last over two days.

– and detect the radiation from stars, hot (ionized) gas, cool (neutral) gas *and* dust heated by nearby stars. At longer wavelengths the detectable objects become progressively colder until all that can be seen is the microwave background from the big bang. For comparison, optical CCDs are sensitive in the range 0.3 to 1.0 micron.

The entire camera, with filters and lenses, must be cryogenically cooled to incredible sub-zero temperatures around minus 196°C

using a combination of liquid nitrogen and liquid helium to eliminate the infra-red or 'heat radiation' from the camera components themselves; the camera must also be mechanically rigid. This is an engineering feat in itself! IRCAM weighs over 70 kg and most of its components and mechanisms are hidden inside a large vacuum chamber. Like most modern instruments, IRCAM is fully automated and operated from a console in the telescope Control Room.

Specially developed software – computer programmes – make the camera very easy to use. Infra-red images are stored in digital form on magnetic disks and tape, and are also displayed for immediate appreciation on false-colour computer screens at the telescope. By false-colour is meant the following. Consider an ordinary black and white picture. It is actually made up of many different shades of grey – each shade of grey representing the brightness of that part of the scene. Suppose instead of using a certain shade of grey for a certain brightness we use a colour, and then adopt a very different colour for the next closest shade of grey and so on. We end up with a picture in which the colours represent the brightness of the scene rather than the wavelength of the radiation. This is called 'false-colour-coding' and it can be used to dramatic effect to highlight subtle changes in brightness which would be lost if represented merely by a tiny change in the shade of grey.

Among IRCAM's unique features are, three possible image scales (0.6", 1.2" and 2.4" per pixel) which are determined by the choice of internal re-imaging lens selected prior to cool-down of the camera system, and modes allowing IRCAM to be used in conjunction with a polarimeter and/or a Fabry-Perot interferometer. The former enables IRCAM to distinguish light which has become polarized – by interaction with a magnetic field or with tiny scattering particles – whereas the latter acts as a tunable, very narrow spectral filter which turns IRCAM into an 'imaging spectrometer'. The detector itself is operated at a temperature of 35 K, i.e. at -238°C , and IRCAM is kept operational for many weeks at a time. Because IRCAM can observe through thin clouds it is a handy 'backup' instrument even when it is not the prime instrument for that night!

In general IRCAM is used like an optical CCD camera – timed exposures are taken with sufficient duration to overcome any electronic readout 'noise' but not so long as to result in saturation.

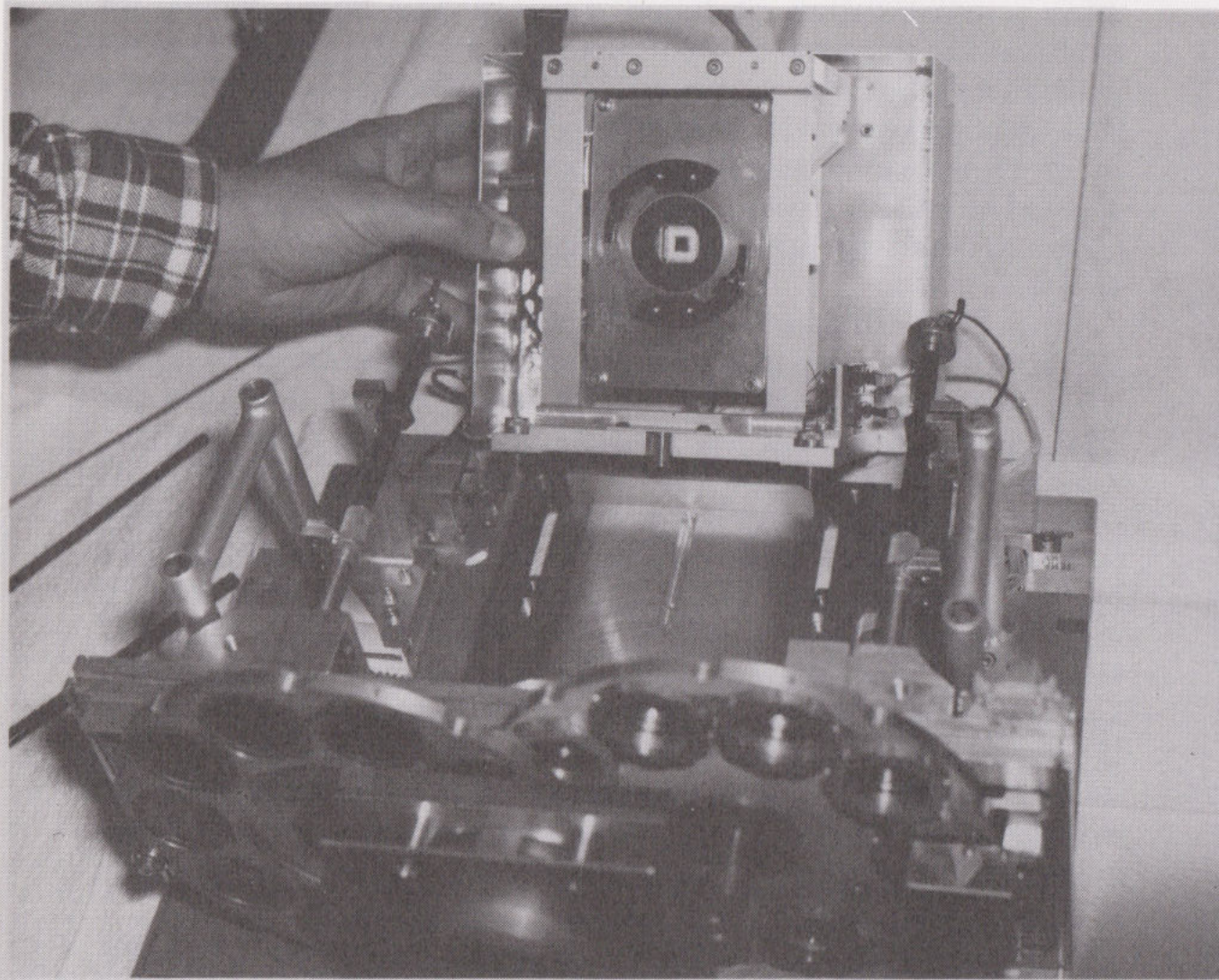


Figure 2. Part of the complex inner structure of IRCAM showing filter wheels and detector module. Remember that ALL of these components – even the moving parts – must be kept very cold, otherwise the infra-red array will detect their heat radiation instead of that from distant sources in the cosmos!

Each image of an infra-red scene is then ‘corrected’ by dividing the signal in each pixel by the value in a special image of blank sky called a ‘flat-field’; a flat-field is an image in which every pixel has been exposed to exactly the same level of illumination. This process normalizes all the individual picture elements to the same sensitivity and is crucially important in determining how faint the IRCAM can ‘see’. So far, this correction process has been carried out to a level of 7 parts in 100,000, which means that infra-red objectives more than 10 magnitudes fainter than the infra-red sky

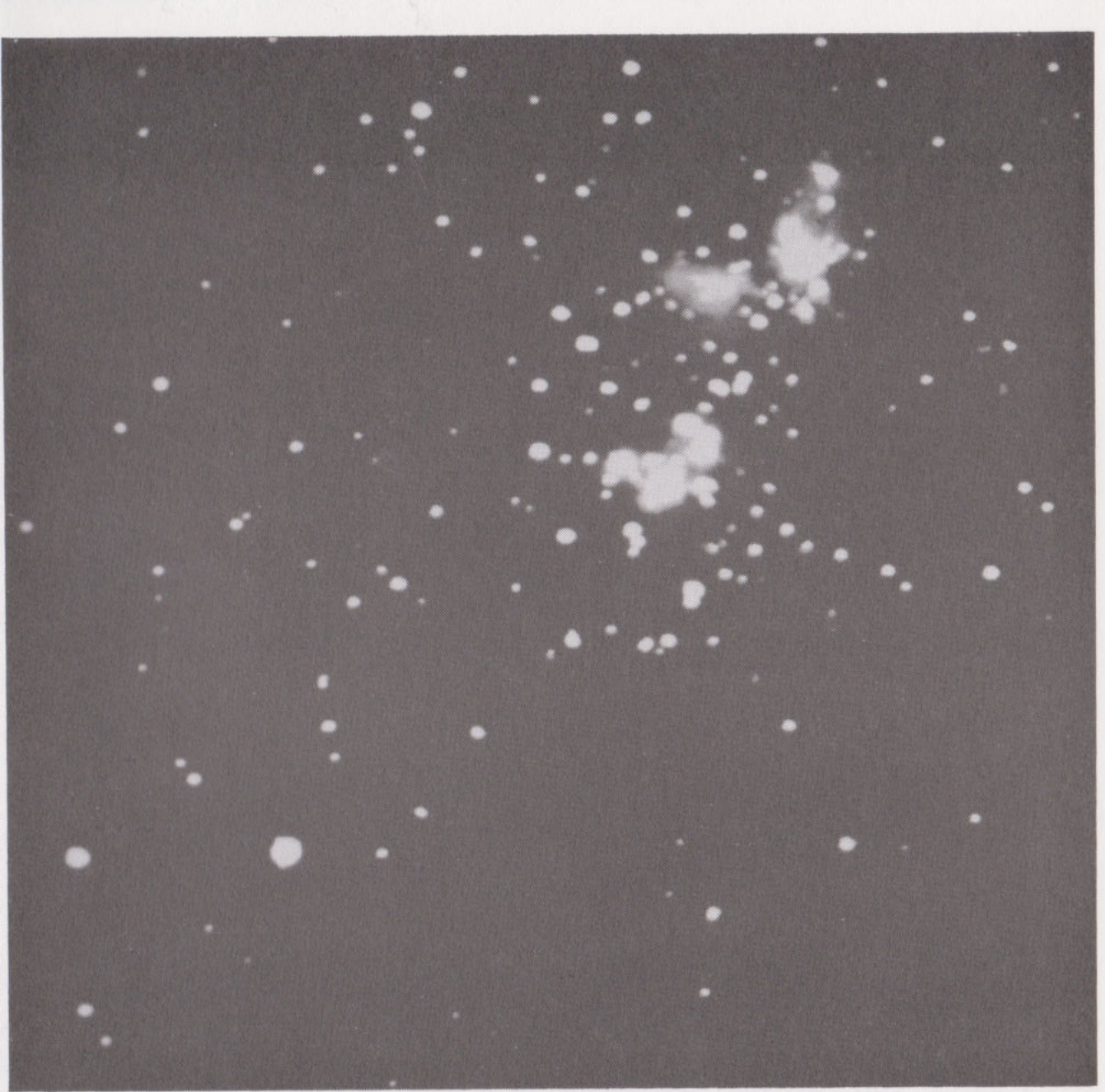


Figure 3. An infra-red image of M42, the Great Nebula in Orion. The penetrating power of infra-red light cuts through the glare of the optical nebula to reveal hundreds of embedded stars clustered around the Trapezium.

can be detected! This is actually better performance than many optical CCDs.

Results from IRCAM have spanned the entire range of astronomical phenomena. From planets and comets, to active galaxies and distant clusters with cosmological implications; from star formation and early stellar evolution to planetary nebulae and supernova remnants; from elusive 'brown dwarfs' to black holes at the centre of our galaxy. A few of the many examples of significant new findings are (i) the near infra-red images showing the Orion Nebula star formation region; (ii) high resolution images of the bright emission from high velocity hydrogen gas at the Galactic

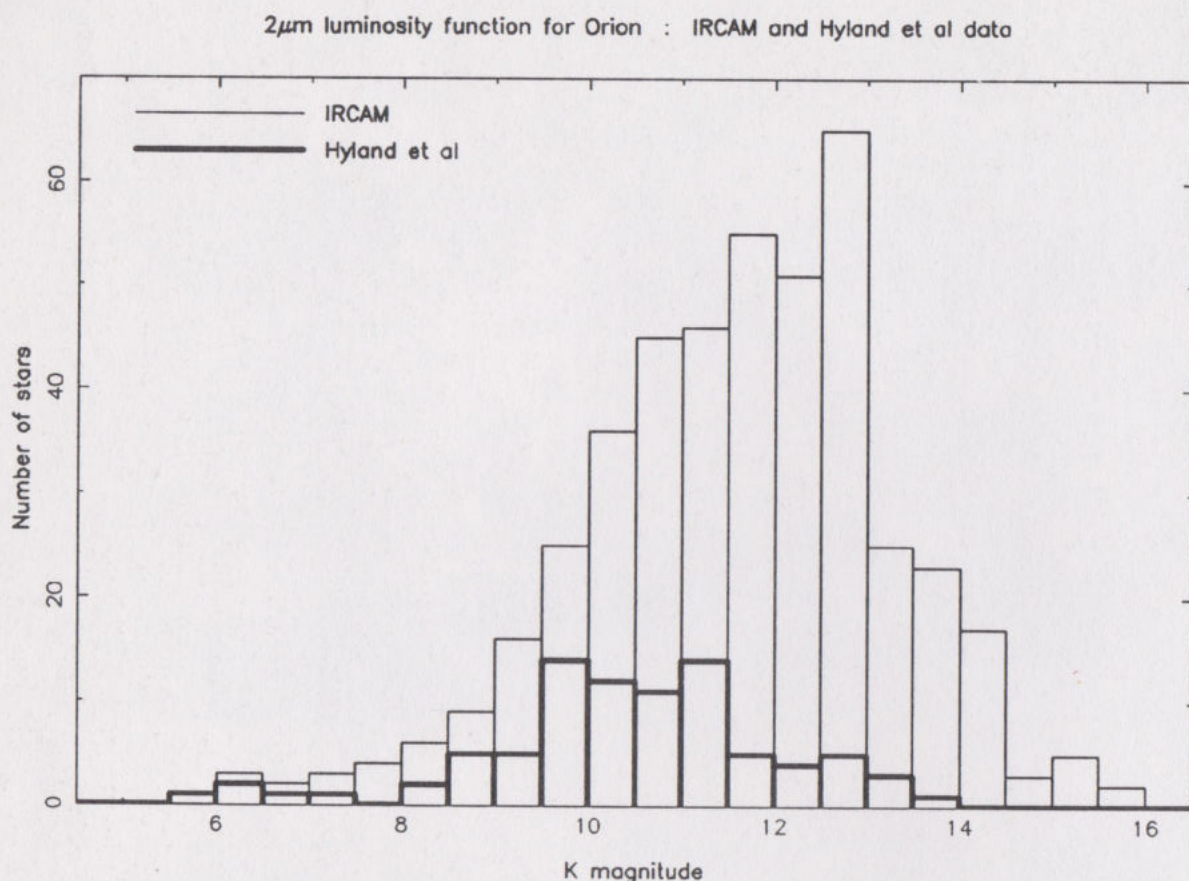


Figure 4. A plot of the number of stars versus their apparent magnitude at 2.2 microns. The brightest stars are OB stars with masses 10 to 50 times that of the Sun, whereas the faintest appear to be stars of about one solar mass.

Centre; and (iii) the first image of a large neutral envelope of molecular hydrogen surrounding a planetary nebula.

From infra-red images of star-formation regions such as M42 we can derive the distribution of luminosities, which in turn yields an estimate of the distribution of the masses of the population of young, hidden stars. The faintest objects in such a plot are 10x fainter than any known before and may be young solar-type stars.

The centre of the Milky Way is even more heavily obscured. Over 26,000 light-years of gas and dust thoroughly restrict our optical view of those innermost regions. In the near infra-red however, the obscuration is minimal, and one can observe directly the motion of high-velocity streamers of ionized hydrogen gas in the core of the Galaxy. Such observations, although difficult, will provide clues to the dynamics of the galactic centre and the debate about the existence of a black hole.

Planetary nebulae are formed by the expulsion of the outer

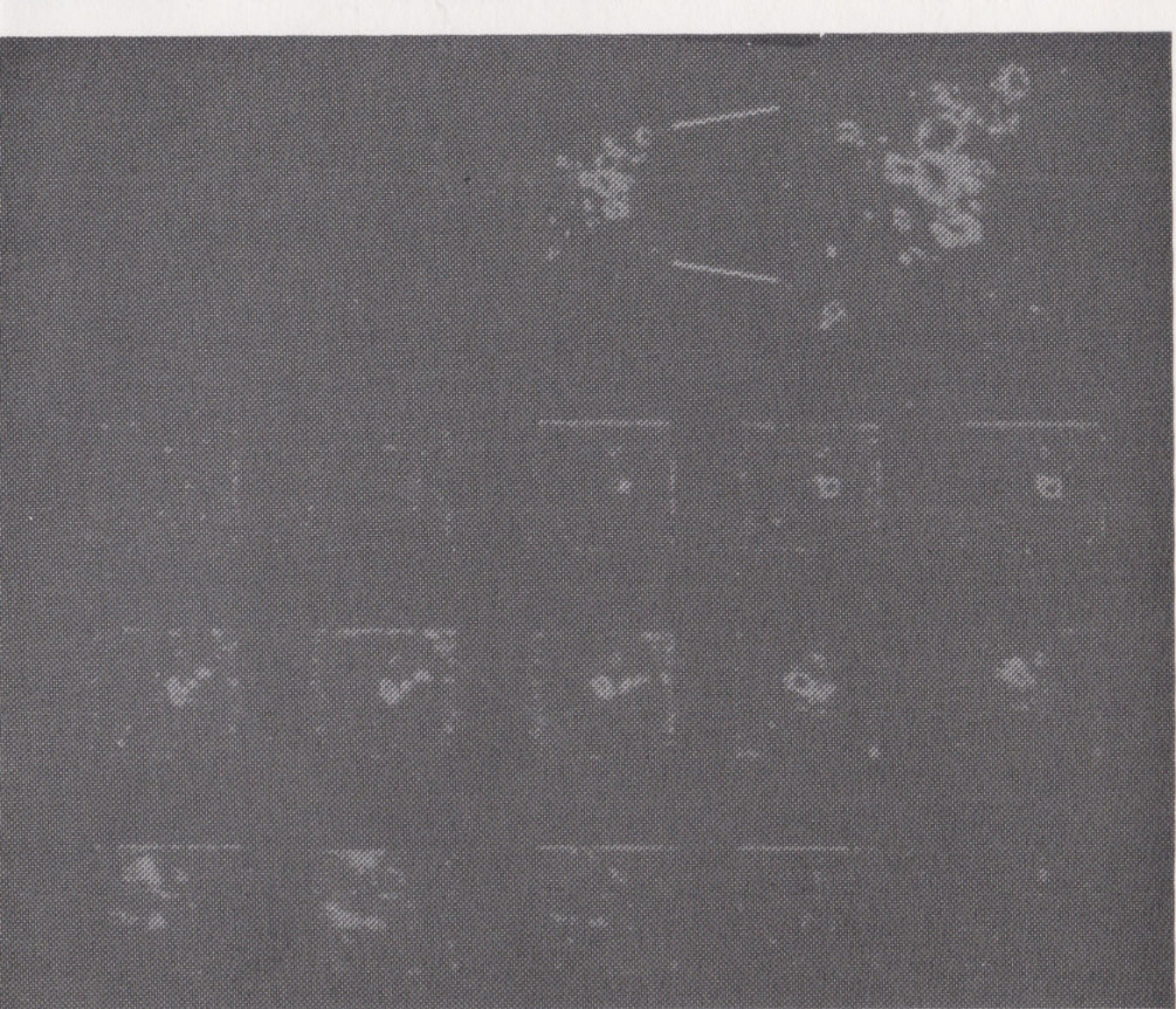


Figure 5. A group of fifteen separate images of the centre of our own Galaxy. Each picture is centred on the same point but IRCAM was 'tuned' to a different narrow wavelength window using the Fabry-Perot interferometer. Because of the Döppler effect, each narrow interval in wavelength corresponds to a narrow window in velocity. In other words, each picture is a snapshot of the distribution in space of hot, high-speed gas clouds near the Galactic Centre.

atmosphere of stars which have evolved into red giants. The remnant object invariably produces a hot stellar wind which is so fast that it catches up on the material lost earlier. The interaction of the hot wind and the cool, neutral gas – which is mostly molecular hydrogen – results in a 'shock wave' which heats the molecular hydrogen and excites molecular 'vibrations'. When the hydrogen molecule vibrates in this way it emits a characteristic spectrum of radiant energy which can only be detected in the infra-red. IRCAM images of NGC 7027 in the light of the strongest of these 'vibrational lines' revealed the existence of an immense cloud of invisible, neutral material around the optically visible part of this planetary nebula. This finding is significant in

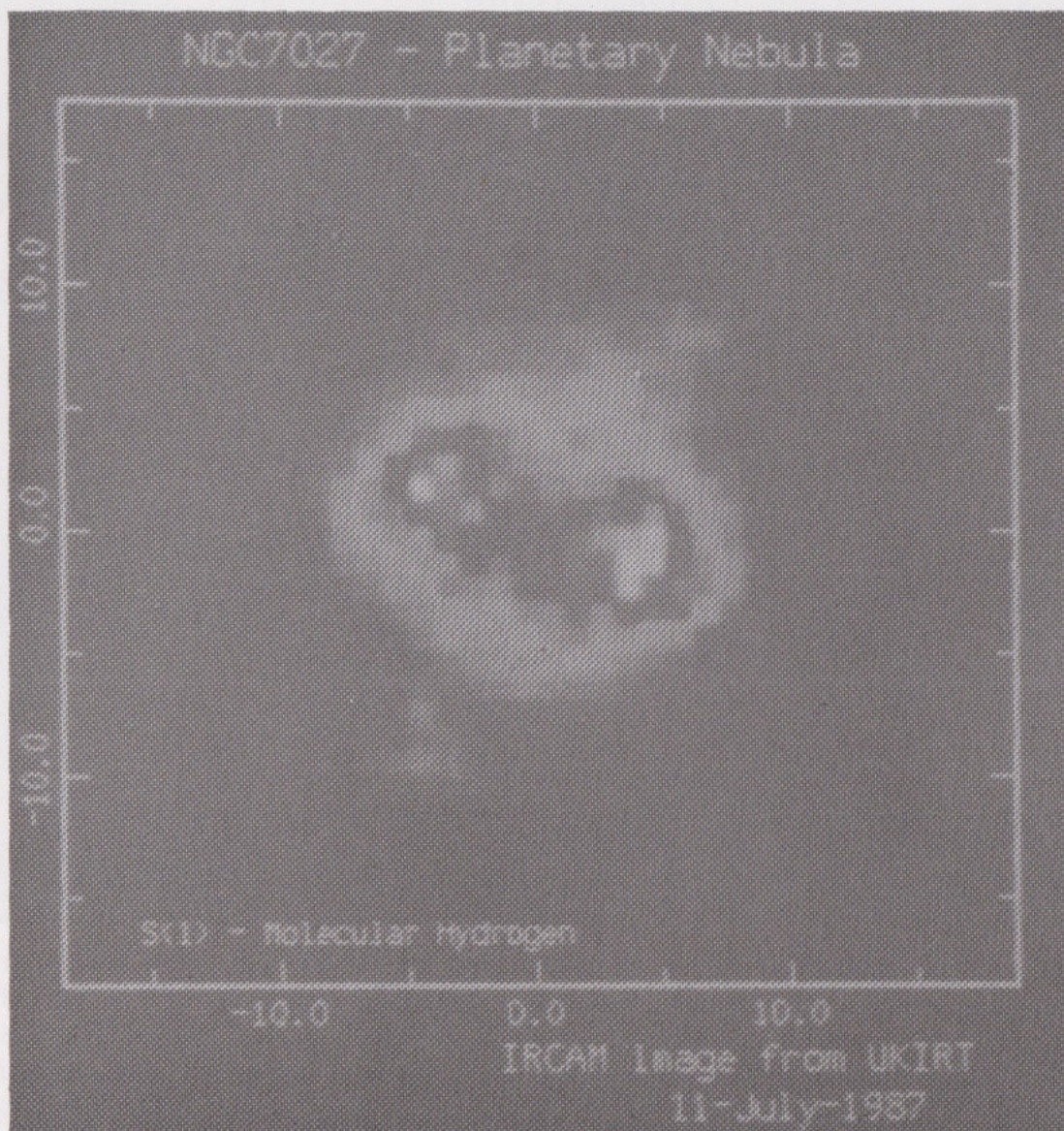


Figure 6. An image of the planetary nebula NGC 7027 in the light of the emission from shocked molecular hydrogen. The IRCAM picture reveals a region, dumb-bell in shape, of intense emission and an extensive envelope of cool molecular hydrogen gas. Such a large region was unexpected on the basis of optical measurements which show NGC 7027 as a peculiar, lop-sided blob of light. The double-lobe structure is hidden by dust.

the discussion of the masses of the progenitor stars, and in models of the forces which shape planetary nebulae.

The next step is to equip an infra-red spectrometer with an array camera and to consider infra-red array instruments for even longer wavelengths to probe yet colder regions of space. An important future use of infra-red cameras will be on the new generation of Very Large Telescopes now being planned, since at infra-red

wavelengths it should be possible to achieve diffraction-limited performance and gain by the increase in telescope collecting area.

Imaging the infra-red sky is a long-awaited dream which became a reality in 1987.

IRAS galaxies— What are they?

KIERON LEECH

With the 1983 launch of the joint American/Dutch/British Infra-Red Astronomical Satellite, IRAS, astronomers gained new eyes with which to observe the universe. IRAS carried out the first mid- and far- infra-red (IR) sky-survey at wavelengths of between 12 and 100 μ m, observing about 95 per cent of the sky with a nominally constant sensitivity. The survey lasted just under a year, before the helium used to cool the telescope and detectors ran out. About two hundred and fifty thousand IR sources were detected and catalogued during this time. The most important catalogue was the Point Source Catalogue (PSC), a catalogue of sources smaller in angular diameter than about 2 arcmin, which appeared as point sources to IRAS. Most of the sources in this catalogue were identified as stars in our Galaxy, but a considerable number were other galaxies. By comparing the positions of the IR sources with positions of known galaxies, astronomers were able to pick out the galaxies detected by IRAS. The majority of these galaxies were normal spiral galaxies within ≈ 200 Mpc (Mpc is an abbreviation for Megaparsec, where a parsec is about 3.26 light-years and Mega is Greek for million) of the Sun, IRAS detecting the IR radiation from dust heated by starlight in the galaxies. Very few elliptical galaxies were detected, because most ellipticals contain little dust. A puzzle emerged, however, in that a small fraction of the spiral galaxies detected by IRAS were found to be as luminous as quasars, the most luminous objects in the Universe, but to have spectra similar to ordinary, low luminosity H II regions (regions of star formation dominated by young, hot stars). In addition, a considerable fraction of 'warm' IRAS sources, those with 12 and 25 μ m fluxes higher than their 60 μ m fluxes, were apparently Seyfert galaxies, smaller brothers of quasars. Two ideas emerged as to the cause of high IR luminosities observed in some galaxies. One was that these galaxies were quasars obscured by dust, the other that they were galaxies in which a large amount of star formation had occurred in a very short period of time – starbursts. Interactions with other galaxies, or having bars in the galaxies, is

thought to trigger star formation, because both cause the movement of gas into high density regions (usually near the nucleus) suitable for star formation.

Because of this puzzle, astronomers at the Royal Greenwich Observatory (RGO) and Queen Mary College were motivated to collaborate and survey the sources detected by IRAS for two main reasons: one cosmological, the other astrophysical:

1. Because the IRAS survey was the first sensitive and uniform survey over the whole sky and since most of the sources observed away from the galactic disk were galaxies, it became obvious that the Point Source Catalogue could be used to trace the distribution of galaxies in the Universe. While important information could be obtained from counting the number of galaxies in different regions of the sky, to obtain the maximum information from the PSC would require a redshift survey so that the distances to the objects could be determined.
2. What fraction of the galaxies observed by IRAS were as luminous as quasars? Which is the correct theory for the energy source in these galaxies, starbursts or obscured quasars? Were there different classes of these objects, powered by different energy sources?

To answer these questions the joint group embarked upon a redshift survey of IRAS galaxies. This would enable answers to the cosmological questions to be quickly obtained and give a luminosity for each object, from which the highest luminosity sources could be extracted to observe in greater detail at a later date.

Stars, because they have surface temperatures in the range 4000–50,000 K, radiate more energy at the shorter wavelengths of 12 and 25 μm than at 60 μm . Most of the IR emitted from galaxies, however, comes from cool, 25–100 K, dust radiating more at 60–100 μm than 12 and 25 μm . Since stars are concentrated towards the Galactic plane, while galaxies are randomly distributed over the sky, the ratio of galaxies to stars in a small region of the sky increases away from the Galactic plane. Hence, to search through less sources and to have a higher chance of finding galaxies, it is best to use regions in either the North Galactic Pole (NGP) or the South Galactic Pole (SGP) and to look for objects that radiate most of their energy at 60 μm . Thus a small region of the NGP was selected and about 400 sources from the list of IRAS

sources were chosen with a set of selection criteria designed to ensure most were galaxies. About half of the sources in this list were previously catalogued galaxies, so armed with the accurate positions of the remaining unobserved sources, obtained by measuring Palomar Observatory Sky Survey plates, we travelled in May 1985 to the Spanish island of La Palma to use the 2.5-m Isaac Newton Telescope (INT). The uncatalogued galaxies were observed using the Durham/RGO Faint Object Spectrograph, an instrument specially designed for obtaining the spectrum of a faint object very quickly, using a Charge Coupled Device cooled to liquid nitrogen temperatures as the detecting device. From the observed galaxies and previously catalogued galaxies a complete sample of 300 galaxies was obtained for the redshift survey. The spectra of all the galaxies we observed were looked at in greater detail to try and determine what type of galaxies they were.

Number counts of IRAS sources in the North and South Galactic Poles indicated a statistically significant excess of galaxies in the NGP compared to the SGP, an anisotropy of galaxies, over the sky. The redshift survey showed that the galaxies contributing to this excess were further away than the local supercluster, and thus the anisotropy is real, having important implications for cosmology. It also showed that there were more IRAS galaxies in the Universe than Seyfert galaxies. The major result for the redshift survey, however, was that the value of Ω_0 , the rate at which the expansion of the Universe is slowing down, was found to be 1, the critical value. This is in disagreement with other experiments, which give a lower value. Ω_0 smaller than 1 means that the Universe will continue to expand for ever, an open Universe, while a value higher than 1 indicates that the Universe will eventually collapse back on to itself, a closed Universe. An Ω_0 of 1 shows that the Universe will never collapse back into itself but is closed – it is said to be a flat Universe.

The majority of the newly observed IRAS galaxies showed low excitation spectra, similar to H II regions, and exhibited strong emission lines. Only 6 per cent of the galaxies, predominantly high luminosity galaxies, showed high excitation lines and all of these were likely Seyfert galaxies. The more luminous galaxies were also found to have warmer IR colours than the lower luminosity galaxies, something which is still unexplained. The luminosity of one of the important emission lines, $H\alpha$, was found to correlate with the IR luminosity of the galaxies. The strength of $H\alpha$ is an

optical measure of the power source, be it star formation or Seyfert-like activity. The fact that this is correlated with the IR emission means that it is likely they come from the same source, so by studying the optical emission we can learn about the source of the IR emission. It may, however, be a case of everything correlating with everything else – larger galaxies with higher IR emission have more stars in with which to produce $H\alpha$ emission lines.

Several facts indicated that the majority of IRAS sources are high opacity regions. First, while we are assuming blue stars or a blue active nucleus for the energy source, there is no sign of blue light in most of the galaxies. Second, while $H\alpha$ is generally seen, there is usually no sign of another hydrogen line that should have about one third the strength of $H\alpha$: $H\beta$, indicating heavy extinction towards the emission line region. Third, the typical luminosity ratio of IR to H emission is several thousand orders of magnitudes larger than would be expected from recombination theory – most galaxies have values in the region of ten to a hundred. These three facts indicate that the majority of photons that excite the gas, ultra-violet (UV) photons, are absorbed by dust and thus cannot excite the gas. Whatever the underlying power source, it is usually well hidden, and essentially all of the energy is emitted in the IR.

Because our sample was an incomplete group of galaxies from the IRAS sample (it excluded, for example, most low luminosity galaxies) we could not use it to make any definite statements about IRAS galaxies in general. Several other groups of astronomers had carried out similar projects, but they all suffered from similar problems. The general consensus was that the majority of IRAS galaxies were starbursts, but it was not known what triggered the starburst. Collisions and interactions between galaxies were put forward as a possible triggering mechanism, but no survey had been carried out to check this in a systematic manner. Similarly, while it was known that a few of the highly luminous galaxies were active galaxies (Arp 220, a giant interacting galaxy, was one such candidate), the total fraction of Seyferts amongst the IRAS galaxies was unknown. Neither was it clear if they dominated the high luminosity groups. Some astronomers claimed that either all high luminosity IRAS galaxies were tidally induced starbursts or obscured quasars. To try determine the relative fraction of active galaxies and starbursts we decided to study a complete sample of

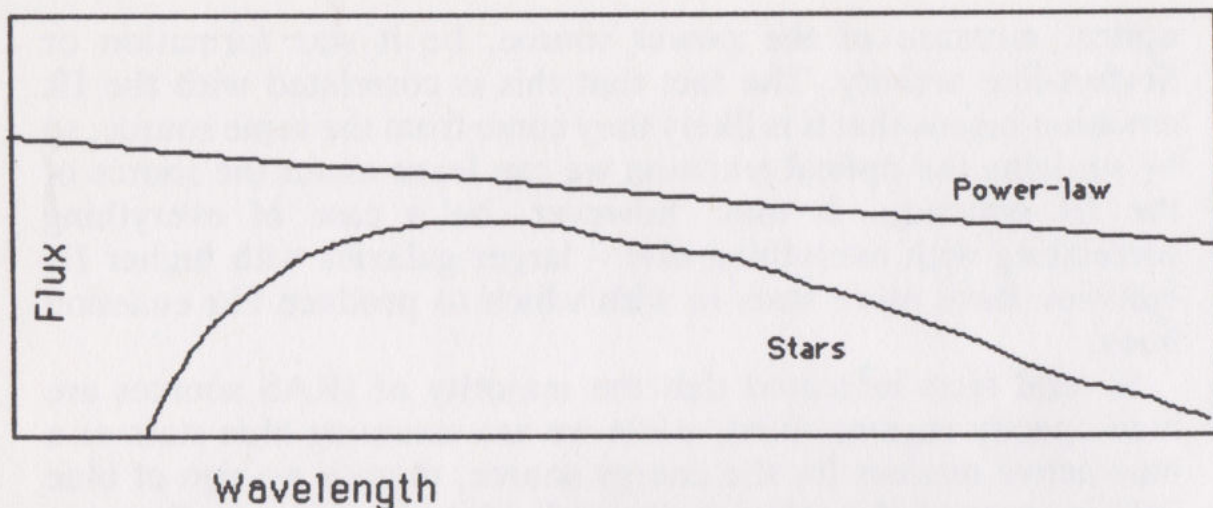


Figure 1.

61 galaxies, by obtaining broad band CCD images and moderate-resolution IPCS spectra.

CCD images, taken in February 1986, indicated that the fraction of IRAS sources that are galaxies merging or interacting with another galaxy increases with the IR luminosity of the source. The theory that all high-luminosity IRAS galaxies are interacting was shown to be incorrect, because while high IR luminosity galaxies are more likely to be interacting than low-luminosity galaxies, some of the highest IR luminosity galaxies are not apparently interacting.

IPCS spectra, obtained in June 1986, also showed that most of the galaxies had spectra similar, but not identical, to H II regions (see page 166 for an explanation of the spectral classification of galaxies). Only about 20 per cent of the sample galaxies were Seyferts. The IRAS starburst galaxies were generally of lower excitation than optically selected starburst galaxies, such as Markarian galaxies. The IPCS spectra corroborated most of the conclusions drawn from the earlier run, confirming that most of the galaxies' energy was emitted in the IR and that they were heavily reddened, but indicated that Seyfert-like galaxies did not comprise the majority of IRAS galaxies in any particular IR luminosity range.

Combining the results of the IPCS and CCD data enables us to describe what IRAS galaxies are. While the low luminosity galaxies are mainly ordinary H II region-like galaxies, the majority of high IR luminosity galaxies are either active galaxies, in the

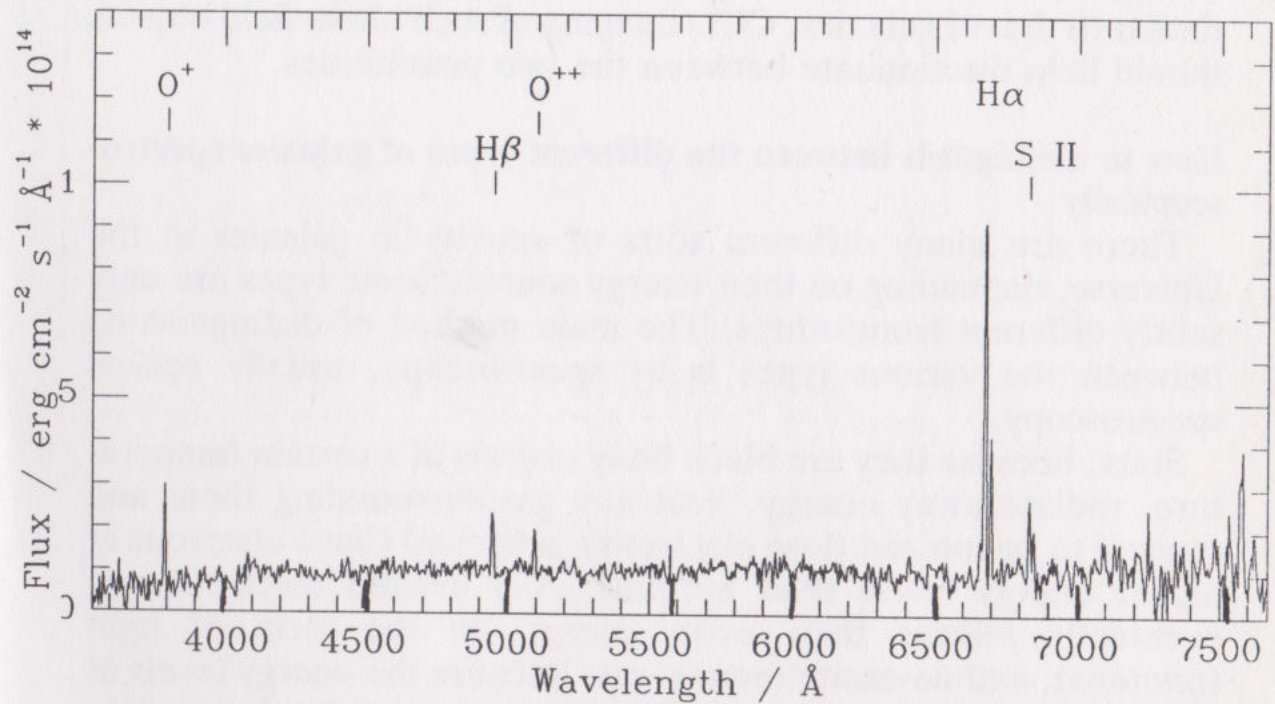


Figure 2. This is the spectrum of an H II region. The galaxy has an IR luminosity more than 10^{11} that of our Sun.

sense that they exhibit Seyfert-like activity, or are interacting galaxies exhibiting H II region-like spectra – many are tidally induced starbursts. Figure 2 shows the number of interacting and active galaxies as a function of IR luminosity. The fraction of active galaxies remains almost constant with IR luminosity, but the fraction of interacting galaxies increases dramatically. Some high IR luminosity galaxies, however, show no signs of being either active or interacting. Why these should have such a high IR luminosity is a mystery and we are carrying out work to try and determine this. If they are starbursts, what is triggering the star formation if they are not interacting?

More studies need to be made of IRAS galaxies. Questions that still have to be answered include how the size of the IR emitting region correlates with the size of the optical emission line region – is it larger, smaller or the same size? This will tell us if there are any regions so obscured we cannot see them in the optical. There is also a puzzling class of objects known as blank field objects. These are cases where an IR source exists with IR colours similar to those of galaxies, but no optical counterpart is visible on sky survey plates. These are either the most IR luminous galaxies, or unusual cases where the cirrus (dust in our Galaxy) has IR colours

similar to that of galaxies. CCD imaging of such blank field objects should help discriminate between the two possibilities.

How to distinguish between the different types of galaxies spectroscopically

There are many different sorts of activity in galaxies in the Universe, depending on their energy source. Some types are only subtly different from others. The main method of distinguishing between the various types is by spectroscopy, usually optical spectroscopy.

Stars, because they are black body objects at a certain temperature, radiate away energy, heat any gas surrounding them and cause it to be ionized (lose electrons) or excited (have electrons at higher energy levels than normal). Any excited electrons will eventually release their extra energy, in the form of light (photons), and de-excite themselves. Because the energy levels of atoms are well defined, these photons are only emitted at certain wavelengths and may be detected by astronomers on Earth. Any other power sources, such as black holes, will also emit enough energy to ionize and excite the surrounding gas, but because they are not black bodies different amounts of radiation come out at different wavelengths compared to stars (*see* Figure 1), thus the gas around them is ionized differently. When astronomers observe the spectra of objects they are really looking at the emission lines from the gas superimposed on the light that ionizes the gas.

Illustrated here are two spectra. Figure 2 is of an H II region, and Figure 3 that of a Seyfert galaxy. H II regions are small (a few parsec sized) regions of space where stars are being born and are thus filled with lots of young, very hot stars with surface temperatures in the region of 50,000 K. These stars excite and ionize hydrogen, oxygen and sulphur in the surrounding gas so that in its spectra we see emission lines from hydrogen, singly and doubly ionized oxygen and singly ionized sulphur. The spectrum of the Seyfert galaxy is totally different. Here the energy source is matter heated to high temperatures as it spirals in around a black hole. The emission lines from the gas are much broader because they are Doppler broadened as they fall in and the relative strengths of the emission lines are different. Here doubly ionized oxygen is much stronger relative to hydrogen than it was in the H II region, and other lines have appeared such as neutral oxygen. These differences between the strengths of various emission lines, qualitatively

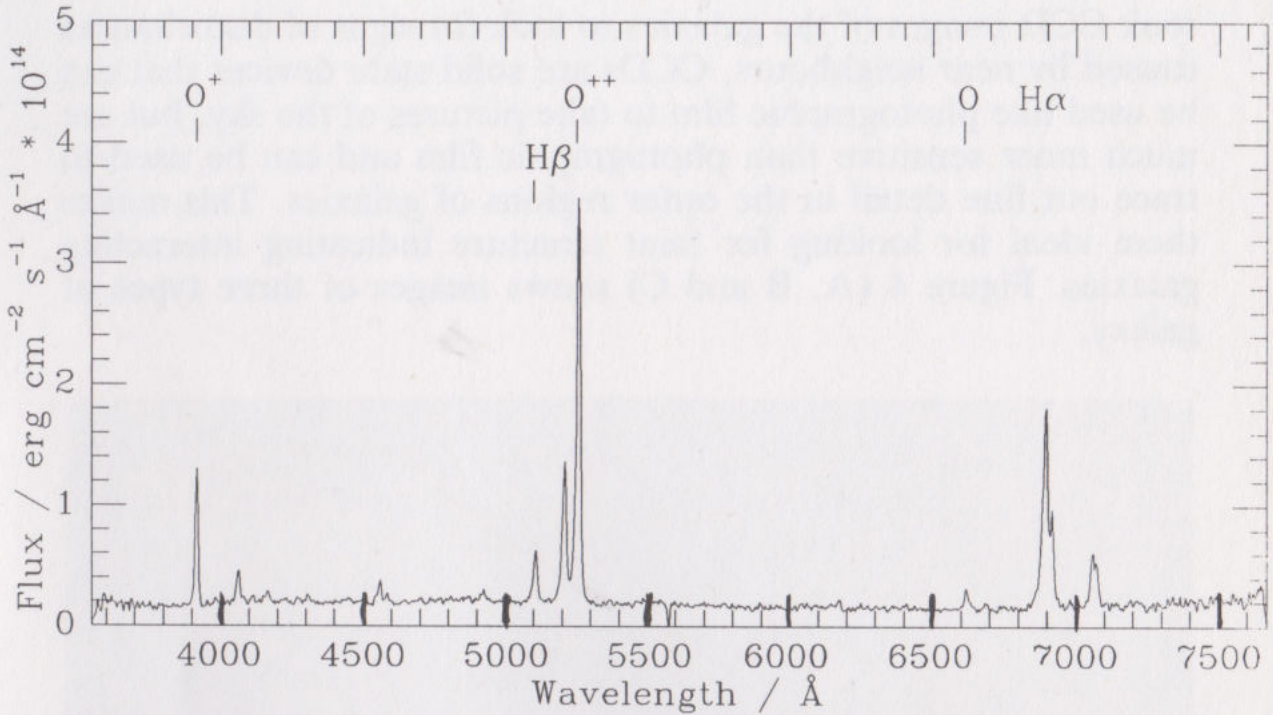


Figure 3. This is the spectrum of a Seyfert galaxy from the sample. It has an IR luminosity $3 \cdot 10^{11}$ that of the Sun. It has stronger $H\beta$ relative to O^{++} and broader emission lines compared to the spectrum of an H II region (see figure 2).

expressed, tell astronomers what each galaxy is – although there is no general consensus between astronomers as to exactly what ratios different types of galaxies should have!

One of the many instruments used by astronomers to obtain spectra is the Image Photon Counting System (IPCS), a very sensitive detector capable of detecting individual photons. Marrying this with the 2.5-m primary mirror of the INT and the clear skies of La Palma produces an excellent system for obtaining spectra of faint objects.

Taking a galaxy's picture

Determining if a galaxy is interacting with another is sometimes difficult. There are some distinct signs to look for. Most galaxies are well ordered structures, so if you find one that looks chaotic with tails or bridges and another galaxy nearby, there is a good chance they are interacting. It is sometimes difficult to distinguish between this and two galaxies that lie in the same line of sight, making the nearest one look random and chaotic. While various techniques may be used to tell if galaxies are interacting, we simply

took CCD images of the galaxies to look for signs of disturbances caused by near neighbours. CCDs are solid state devices that can be used like photographic film to take pictures of the sky, but are much more sensitive than photographic film and can be used to trace out fine detail in the outer regions of galaxies. This makes them ideal for looking for faint structure indicating interacting galaxies. Figure 4 (A, B and C) shows images of three types of galaxy.

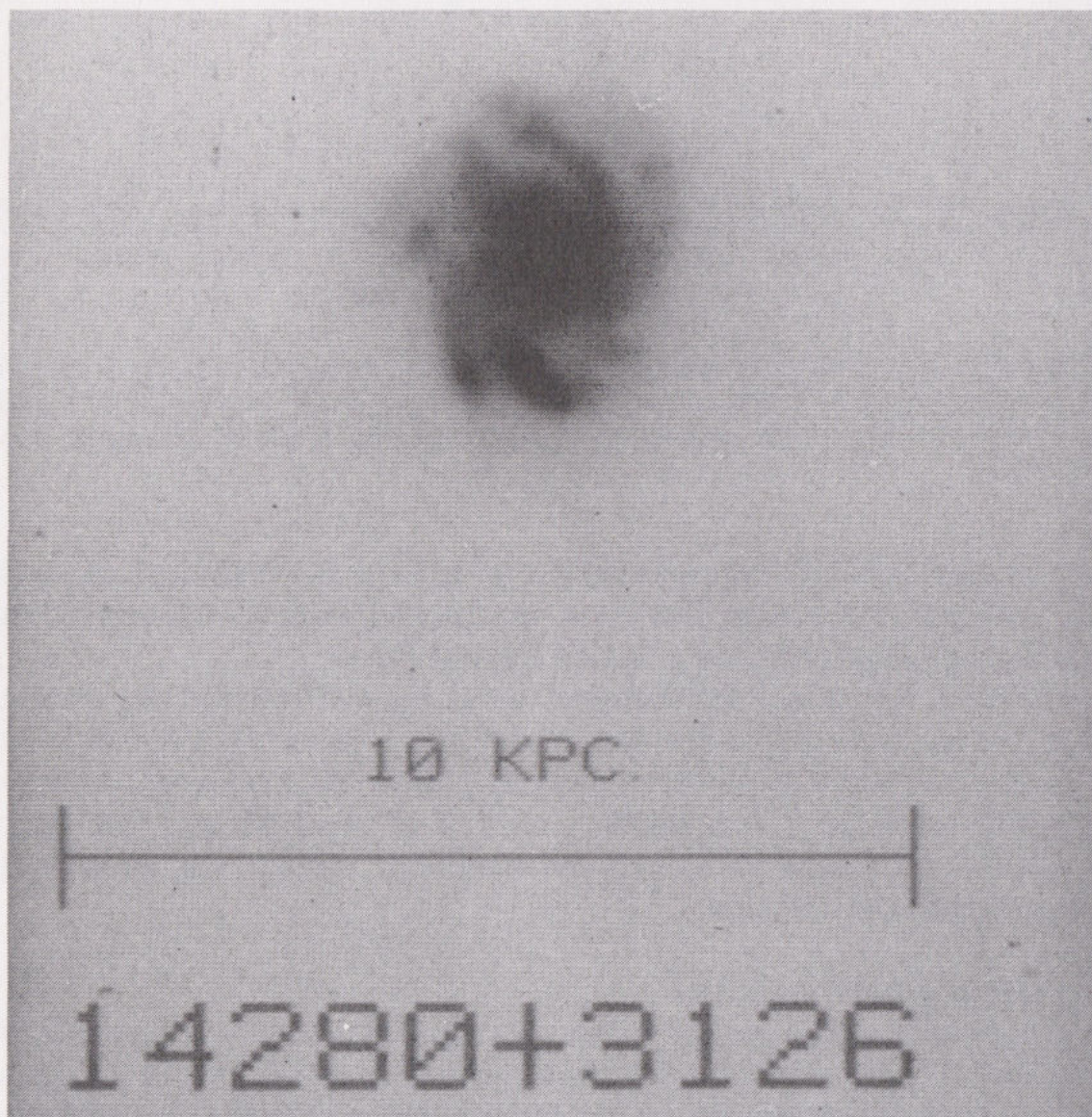
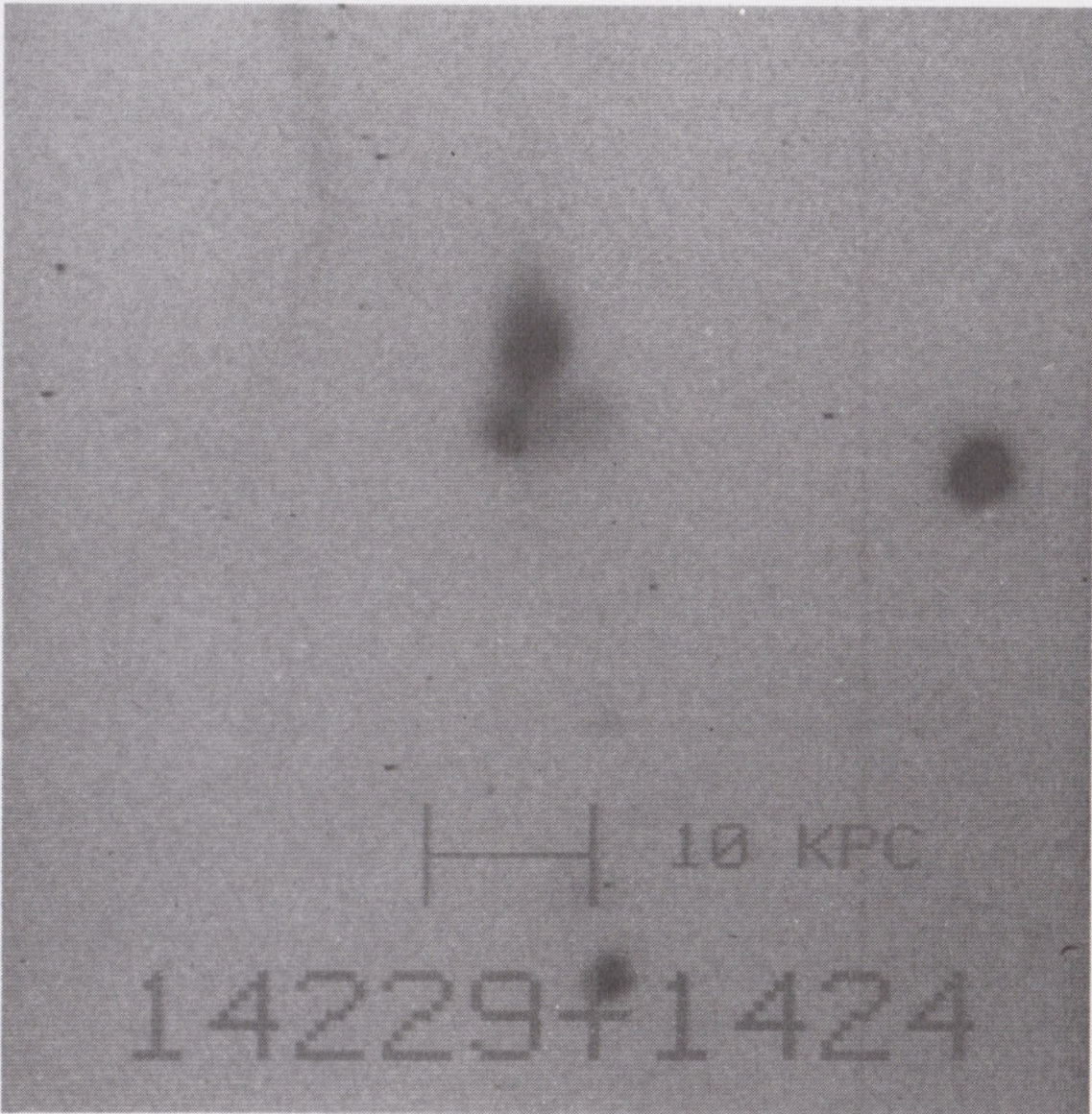
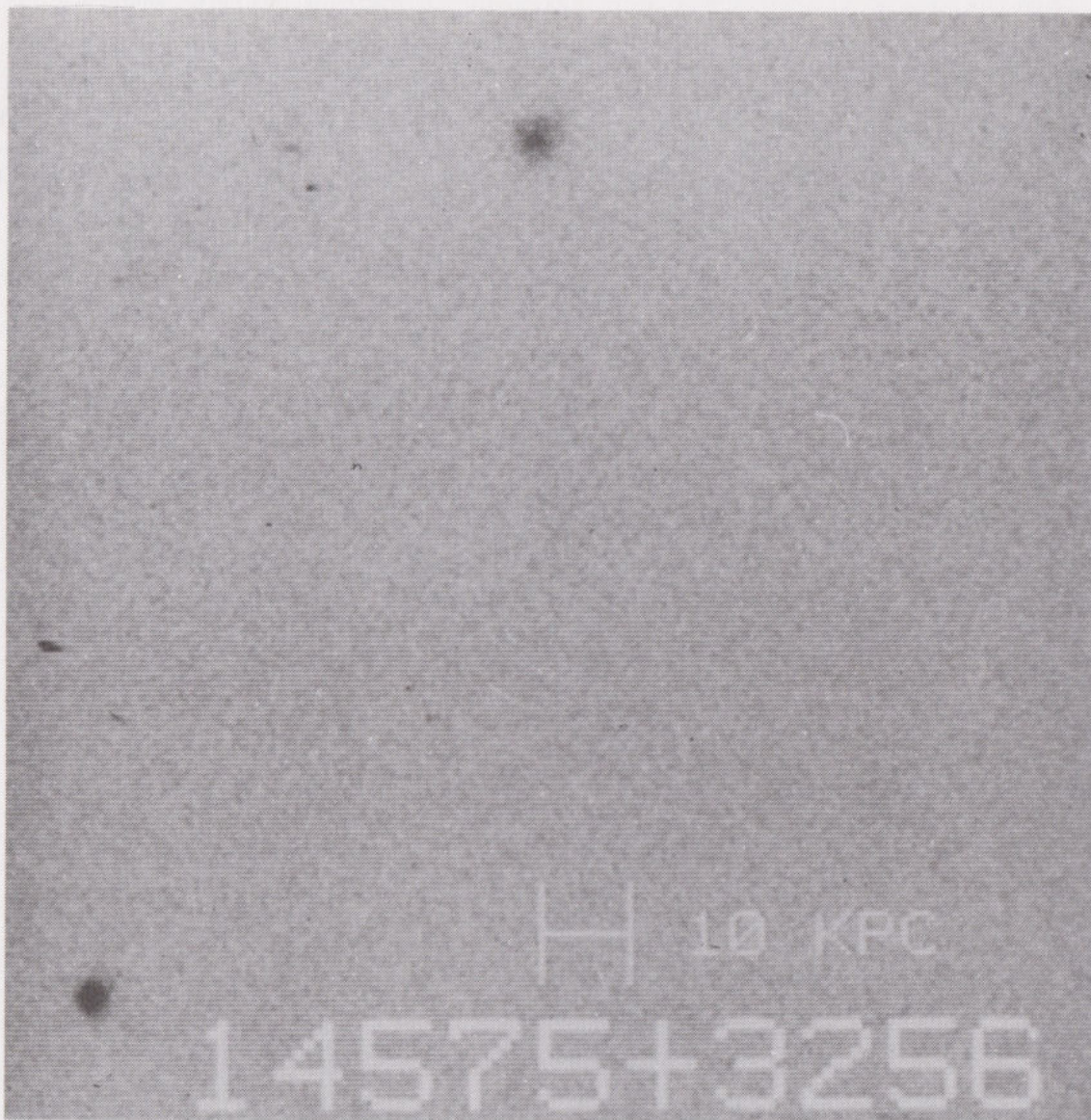


Figure 4. A. shows a non-interacting galaxy. The bulges in its arms are H II regions.



B. shows an interacting system – both galaxies are much more chaotic than the galaxy in A.



C. This is a galaxy that is difficult to classify. To look at it is only a small blob. Special techniques have to be used to try and bring out any structure in the image to help to classify it.

The author is grateful for the collaboration of Michael Penston, (RGO), Andy Lawrence (Queen Mary College), Michael Rowan-Robinson (Queen Mary College), Roberto Terlevich (RGO), Derek Jones (RGO), Jasper Wall (RGO), and David Walker (Queen Mary College).

The Threat from Space to Darkness at Night

PAUL MURDIN

I was strapped into my seat on the Iberian Airways flight to the Canary Islands when the stewardess handed me a copy of *Newsweek* which made my hair stand on end. An article inside the issue of December 8, 1986 described, in glowing terms, the results of a competition by the Eiffel Tower Company for proposals to launch bright advertising satellites. The satellites included one called the Light Ring which would be a completely new problem for optical astronomers and, possibly, the beginning of the end of ground-based optical astronomy.

For the first time, here was a practical and relatively inexpensive way of creating a satellite so large that it would be able to be seen from the ground as a structure, rather than as a point of light. I could instantly see the vastly increased probability of damage to observations made with upward-looking telescopes, and I resolved immediately to combat this menace.

A hundred years ago, Gustave Eiffel had created his tower in Paris as a highly visible demonstration of the power of engineering science, and the Company which continues to run the Eiffel Tower as a tourist attraction was planning to celebrate the centenary with a project under the name of 'Eiffel Tower in Space'. I had to admit that I could see the imaginative power of the proposal, and the reason why *Newsweek* described it approvingly.

The launching of such a satellite would be a proclamation of the advances of space technology. It would make a conceptual advance in the way satellites could be used to 'decorate' the sky. It would be demonstration of the influence which mankind has over his environment, and his readiness to make advances which control his future. It was a kind of art, and, indeed, one of its main proponents was Pierre Comte who was the leader of a movement called 'Art in Space'. Similar kinds of noble statements had been used in the original debates about whether the Eiffel Tower should

be built – and that structure, as is evident to everyone who visits Paris, had indeed become real.

But the Eiffel Tower was something which affected only the Paris basin. It was something which the people of Paris were entitled to debate and, eventually, to approve. The Light Ring would affect the whole world. So far as I could see, no-one apart from the Light Ring's inventor and its sponsors had been consulted.

I had been a member of a working party on the problems of the protection of the environment around observatories, and this group met soon after the publication of the article in *Newsweek*. The group was organized by the Committee on the Challenges of Modern Society, a non-military branch of NATO. The French chairman of this group, an optical astronomer, gave us copies which he had obtained (we did not ask how) of the entries into the Eiffel Tower's competition. They were full of technical details of the satellites.

The idea behind the Light Ring was very simple. It was not much different from a balloon like the Echo satellite – actually it was a series of one hundred balloons, connected together with hollow tubes in the form of a necklace. The balloon structures would be compressed into a volume of only one cubic metre for launch, and there would be a small amount of water sealed inside the hollows. The compressed balloons would be launched as the secondary payload of an Ariane rocket which was primarily launching a communications satellite, or something similar. After the balloons were injected into orbit, sunlight would warm the balloons, the water inside would evaporate, and the balloons would gradually be pumped up.

Each balloon would be six metres in diameter. When sunlight lit them up, they would appear from the Earth as second magnitude stars. The whole Light Ring structure was intended to inflate to a circular necklace which was eight kilometres in diameter, so it would appear like a hundred stars in an ellipse about 0.5 degree in major axis, the angular size of the Moon. Altogether, the satellite would be about as bright as Venus.

The brightness of the satellite was not, itself, so far as I could see, the major problem. After all, several satellites including Echo were about as bright as this. It was the angular extent, combined with the brightness, which made this particular object a threat to optical astronomy. As the Light Ring moved in orbit over the sky,

it would sweep out a strip which was 0.5 degrees wide and, from one horizon through the zenith to the opposite horizon, 180 degrees long. This summed to an area of 90 square degrees, compared to the 20,000 square degrees in a hemisphere – roughly 0.5 per cent of the visible sky. Thus, if the satellite made daily passes over a given telescope, in the course of a year there was a near certainty (over 80 per cent probability) that it would intrude on the beam of the telescope. It was almost a sure bet that somewhere in the world, a telescope would be affected by the satellite sometime in the year.

Now, if the Light Ring swept into the view of a telescope, the second magnitude appearance of each balloon would certainly destroy the observations which the telescope was then making, its light swamping any view of the faint stars under study. I suppose one could be realistic about this – not all observations are successful, and maybe if someone somewhere had to throw away a bad observation that would not be a desperate problem. But I was very concerned at the possibility that the balloon could destroy the detectors which astronomers use.

To catch the light from distant, faint quasars and galaxies astronomers use equipment which amplifies the light. The Image Photon Counting System (IPCS) used in La Palma and at the Anglo-Australian Telescope is one of many such devices which rely on an Image Tube front end. Photomultipliers are similar.

A photon is detected when it strikes the sensitive photocathode in such a device and ejects an electron from the alkalis with which the photocathode is coated. The electron is accelerated with a high voltage and eventually strikes a phosphor, emitting, say, a million photons, which you can easily see. The Image Tube thus amplifies by a million-fold and makes single photons 'visible'. It is not unusual for the IPCS to sit for, say, ten hours counting photons from a star and end up with a few dozen photons in the astronomical signal from a distant quasar. The problem with the Light Ring would be that its bright signal would be amplified by a million if it passed in front of a telescope equipped with an IPCS-type detector. This bright a signal would literally destroy the photocathode and phosphor: the material would evaporate. It seemed to me that this entitled astronomers to have their say in the debate over the Light Ring.

There was another factor which drove me to combat the Light Ring. If it was within the economic and technical capability of the

Eiffel Tower Company to seek publicity by launching the Light Ring under the guise of 'Art in Space', then it was also possible to launch similar satellites for advertising purposes. If balloons could be constructed to take up the form of a simple ring, then they could also take up the shape, say, of inter-locking hoops like the motif of the Olympic Games, or, with simple additional cross-pieces, a Mercedes Benz symbol. Multi-national companies could mount literally world-wide advertising campaigns if the Light Ring turned out to be feasible. I could envisage a night sky filled with advertising satellites, and no chance at all for astronomers to carry on their work. If this would be a disaster for astronomers, it was scarcely less for the people of the world, stopped for ever from enjoying views of the stars without offensive intrusion.

The first step in the campaign was to tell people of the plans for the Light Ring. I wrote two articles, for *Nature* and the *New Scientist*, which described the Eiffel Tower in Space project, including not only the Light Ring but the runner-up in the competition for ideas. This was an orbiting curved sail called Arsat ('Art Satellite') which focused light on the ground, like a concave mirror. This satellite would not appear as an extended object like the Light Ring but it was much brighter, because it was focused. According to its inventor, it was possible to make these sails so that they were as bright as the Full Moon. Imagine what this would do to telescopic observations!

I gave a talk to the Royal Astronomical Society on the day that the articles were published, and asked the Council to pass a resolution at its meeting that afternoon condemning the Light Ring – it did. I arranged for the press to be at the meeting, and several journalists were there from British papers, and the Press Association. This led to stories of the type 'astronomers were furious today at reports that a new satellite could destroy their observations' – just what was required.

I created a discussion of the Light Ring in the 'parliament' of the Canary Island observatories. This is called the International Scientific Committee and known by its Spanish initials as the CCI. It is a place where the national science organizations of Britain, Spain, Sweden, Denmark, and Germany meet. Since the Light Ring threatened the telescopes on La Palma and Tenerife, the CCI was not happy. In particular, Spain is committed by its international treaties with the other countries to protect the observatories. Spain thus raised the matter at an international level. Its Minister

of Education is on the governing board of the Instituto de Astrofísica de Canarias. He asked pointed questions of the French ambassador in Madrid .

INSU – the French Institut National pour les Sciences de l'Univers (National Institute for the Sciences of the Universe) – was negotiating at that time to join the Canary Island observatories. It plans to build a solar telescope called Themis on Tenerife. INSU's delegates at the meeting promised to convey our concern over the Light Ring back to their president. INSU made protests in the French government, on behalf of all the ground-based astronomers.

I also wrote innumerable letters. I wrote one to the committee of the House of Commons which discusses environmental pollution. Its chairman tabled a Parliamentary question about the Light Ring. A few days later I was contacted by an official of the British National Space Centre. It seemed that there was this crazy idea to put this silly satellite in space, and astronomers were getting upset, and she had to draft a reply for a minister to give in the Houses of Parliament, and did I know anything about this? I did know something, it was not entirely silly, and I drafted a stern reply to the question which I had prompted.

I never received replies to my letters to the Eiffel Tower Company. There were, however, lots of counter-articles from the Space Art proponents. I was amused that, to the astronomers, the proponents of the Space Art satellites would minimize their brightness, while to the sponsors they exaggerated how dramatic they would appear! What was clear to me was that, if a satellite was noticeable enough to be called Space Art, it was too bright for astronomers.

I was surprised at the take-up of interest in the story in the press. I suppose that it had the right elements of combat, futurology, environmental issues, and bizarre fascination to be newsworthy. Journalists who telephoned listened in incredulous silent surprise when I described other plans to pollute space, such as the morbid proposal by the Celestis Corporation in Florida to dispose of the cremated remains of human bodies by launching them in reflective mausolea. I could hear the pens scratching furiously as I described how, before their launch into the universe, the bodies would be compacted to the size of a stock cube by a special, patented process and placed in capsules labelled with name, religion and Social Security number.

There was considerable interest about the astronomers' opinion of the Eiffel Tower proposal in France, of course, and friends sent me clippings from places as far apart as Italy, the USA, and Australia. An Australian journalist ripped into the story with gusto – anything to get at the French after the Australian protests over French nuclear tests in the Pacific. I was amused by some of the quotations which were attributed to me by journalists with whom I had not spoken. One completely fabricated Italian story made me into an English blimp, disdaining the French for imbeciles. In fact, opposition to the Eiffel Tower proposal was as strong in France, amongst ground-based astronomers, as in England and elsewhere. I believe that it was the pressure by their astronomical countrymen which eventually led to the Eiffel Tower Company withdrawing their idea.

The weak point in the Light Ring proposal was that to be commercially viable within the budget proposed, effectively, it relied on a subsidy from the launching and space development agencies. The Eiffel Tower Company could not afford a dedicated launch rocket or the development of the technology involved in proving the balloon materials for space use and the Light Ring would have to be piggy-backed on other projects. It thus needed the co-operation of CNES, the Centre National pour les Études Spatiales (French National Centre for Space Studies) and ESA, the European Space Agency. Both these organizations withdrew their support when they discovered the harm which the project would do, for little purpose, to the astronomical environment. I read about the final capitulation of the Eiffel Tower Company in the US magazine *Science*, published almost exactly one year after the *Newsweek* had alerted me to the problem. Due to international pressure, it said, the company had dropped the proposal, and I breathed a sigh of relief. (The cynic in me wonders whether the company was happy enough at the acres of free publicity which the campaign generated for the centenary of the Eiffel Tower.)

However, I believe that astronomers should not be complacent in this victory. The pressure to exploit space is still there, and can take forms which astronomers will find hard to live with. The Celestis Corporation's project for reflective mausolea is still a threat to astronomy, and is still licensed by the Department of Transportation, the government agency in the USA which is charged with the commercial exploitation of space. The threat here is in the possibly large numbers of satellites which would be

launched. This particular proposal was the subject of a hostile resolution from the International Astronomical Union's general assembly in 1985 in New Delhi, which asserted that no-one has the right to make changes to the environment of the whole Earth without consultation. The IAU will return to the problem at its General Assembly in Baltimore in 1988, and will sponsor a Colloquium on the subject in August.

Eventually, say in the twenty-fifth century, there will be cities orbiting in space. These will far out-shine the Light Ring, and any satellite which is now on the drawing board. It is not, however, reasonable of us to be against the exploitation of space altogether: on the contrary, astronomy has benefited from space exploration by satellite more than most sciences, so far. No doubt there will be observatories, there on the future space-cities, which will have a clearer view of the sky than will ever be possible from down here on the Earth's surface. In the present day, communications satellites bring life-saving and life-enhancing links to us all, including people who live in remote areas. Weather and other remote-sensing satellites have direct effects upon our lives – the examples are innumerable.

What we must have is a way of balancing the possible bad effects of satellite launches against the good. It's not, of course, just a question of light pollution by frivolous satellites such as the Light Ring. Is it right, for example, to launch satellites powered by nuclear reactors, when there is the risk that they will return uncontrollably to Earth? We need an agreed international forum to discuss – and answer – such questions.

Part III: Miscellaneous

Some Interesting Variable Stars

The following stars are of interest for many reasons. The positions are given for epoch 2000. Of course, the periods and ranges of many variables are not constant from one cycle to another.

Star	R.A.		Declination		Range	Type	Period	Spectrum
	<i>h</i>	<i>m</i>	<i>deg.</i>	<i>min.</i>			<i>days</i>	
<i>R Andromedæ</i>	00	24.0	+38	35	5.8-14.9	<i>Mira</i>	409	<i>S</i>
<i>W Andromedæ</i>	02	17.6	+44	18	6.7-14.6	<i>Mira</i>	396	<i>S</i>
<i>U Antliæ</i>	10	35.2	-39	34	5.7- 6.8	<i>Irregular</i>	-	<i>N</i>
θ Apodis	14	05.3	-76	48	6.4- 8.6	<i>Semi-reg.</i>	119	<i>M</i>
<i>R Aquarii</i>	23	43.8	-15	17	5.8-12.4	<i>Symbiotic</i>	387	<i>M+Pec</i>
<i>T Aquarii</i>	20	49.9	-05	09	7.2-14.2	<i>Mira</i>	202	<i>M</i>
<i>R Aquilæ</i>	19	06.4	+08	14	5.5-12.0	<i>Mira</i>	284	<i>M</i>
<i>V Aquilæ</i>	19	04.4	-05	41	6.6- 8.4	<i>Semi-reg.</i>	353	<i>N</i>
η Aquilæ	19	52.5	-01	00	3.5- 4.4	<i>Cepheid</i>	7.2	<i>F-G</i>
<i>U Aræ</i>	17	53.6	-51	41	7.7-14.1	<i>Mira</i>	225	<i>M</i>
<i>R Arietis</i>	02	16.1	+25	03	7.4-13.7	<i>Mira</i>	187	<i>M</i>
<i>U Arietis</i>	03	11.0	+14	48	7.2-15.2	<i>Mira</i>	371	<i>M</i>
ϵ Aurigæ	05	02.0	+43	49	2.9- 3.8	<i>Eclipsing</i>	9892	<i>F</i>
<i>R Aurigæ</i>	05	17.3	+53	35	6.7-13.9	<i>Mira</i>	457	<i>M</i>
<i>R Boötis</i>	14	37.2	+26	44	6.2-13.1	<i>Mira</i>	223	<i>M</i>
<i>W Boötis</i>	14	43.4	+26	32	4.7- 5.4	<i>Semi-reg.</i>	450	<i>M</i>
<i>X Camelopard</i>	04	45.7	+75	06	7.4-14.2	<i>Mira</i>	144	<i>K-M</i>
<i>R Cancri</i>	08	16.6	+11	44	6.1-11.8	<i>Mira</i>	362	<i>M</i>
<i>X Cancri</i>	08	55.4	+17	14	5.6- 7.5	<i>Semi-reg.</i>	195	<i>N</i>
<i>R Canum Ven.</i>	13	49.0	+39	33	6.5-12.9	<i>Mira</i>	329	<i>M</i>
<i>R Canis Maj.</i>	07	19.5	-16	24	5.7- 6.3	<i>Algol</i>	1.2	<i>F</i>
<i>S Canis Min</i>	07	32.7	+08	19	6.6-13.2	<i>Mira</i>	333	<i>M</i>
<i>R Carinæ</i>	09	32.2	-62	47	3.9-10.5	<i>Mira</i>	309	<i>M</i>
<i>S Carinæ</i>	10	09.4	-61	33	4.5- 9.9	<i>Mira</i>	150	<i>K-M</i>
<i>ZZ Carinæ</i>	09	45.2	-62	30	3.3- 4.2	<i>Cepheid</i>	35.5	<i>F-K</i>
η Carinæ	10	45.1	-59	41	0.8- 7.9	<i>Irregular</i>	-	<i>Pec.</i>
γ Cassiopeiæ	00	56.7	+60	43	1.6- 3.3	<i>Irregular</i>	-	<i>B</i>
<i>P Cassiopeiæ</i>	23	54.4	+58	30	4.1- 6.2	?	-	<i>F-K</i>
<i>R Cassiopeiæ</i>	23	58.4	+51	24	4.7-13.5	<i>Mira</i>	431	<i>M</i>
<i>W Cassiopeiæ</i>	00	54.9	+58	34	7.8-12.5	<i>Mira</i>	406	<i>N</i>
<i>S Cassiopeiæ</i>	01	19.7	+72	37	7.9-16.1	<i>Mira</i>	612	<i>S</i>
<i>R Centauri</i>	14	16.6	-59	55	5.3-11.8	<i>Mira</i>	546	<i>M</i>
<i>S Centauri</i>	12	24.6	-49	26	6.0- 7.0	<i>Semi-reg.</i>	65	<i>N</i>
<i>T Centauri</i>	13	41.8	-33	36	5.5- 9.0	<i>Semi-reg.</i>	60	<i>K-M</i>
δ Cephei	22	29.2	+58	25	3.5- 4.4	<i>Cepheid</i>	5.4	<i>F-G</i>
μ Cephei	21	43.5	+58	47	3.4- 5.1	<i>Irregular?</i>	-	<i>M</i>
<i>S Cephei</i>	21	35.2	+78	37	7.4-12.9	<i>Mira</i>	487	<i>N</i>
<i>o Ceti</i>	02	19.3	-02	59	1.7-10.1	<i>Mira</i>	332	<i>M</i>
<i>W Ceti</i>	00	02.1	-14	41	7.1-14.8	<i>Mira</i>	361	<i>S</i>
<i>R Chamæleontis</i>	08	21.8	-76	21	7.5-14.2	<i>Mira</i>	335	<i>M</i>
<i>T Columbæ</i>	05	19.3	-33	42	6.6-12.7	<i>Mira</i>	226	<i>M</i>
<i>R Comæ Ber.</i>	12	04.0	+18	49	7.1-14.6	<i>Mira</i>	363	<i>M</i>
<i>R Coronæ Bor.</i>	15	48.6	+28	09	5.7-15	<i>Irregular</i>	-	<i>Fp</i>
<i>W Coronæ Bor.</i>	16	15.4	+37	48	7.8-14.3	<i>Mira</i>	238	<i>M</i>
<i>R Corvi</i>	12	19.6	-19	15	6.7-14.4	<i>Mira</i>	317	<i>M</i>

R Crucis	12	23.6	-61	38	6.4- 7.2	Cepheid	6.7	F
R Cygni	19	36.8	+50	12	6.1-14.2	Mira	426	M
χ Cygni	19	50.6	+32	55	3.3-14.2	Mira	407	S
U Cygni	20	19.6	+47	54	5.9-12.1	Mira	462	N
W Cygni	21	36.0	+45	22	5.0- 7.6	Semi-reg.	126	M
SS Cygni	21	42.7	+43	35	8.4-12.4	Dwarf nova	±50	A-G
R Delphini	20	14.9	+09	05	7.6-13.8	Mira	285	M
U Delphini	20	45.5	+18	05	7.6- 8.9	Semi-reg.?	110?	M
EU Delphini	20	37.9	+18	16	5.8- 6.9	Semi-reg.?	59?	M
β Doradus	05	33.6	-62	29	3.7- 4.1	Cepheid	9.8	F-G
R Draconis	16	32.7	+66	45	6.7-13.0	Mira	245	M
T Eridani	03	55.2	-24	02	7.4-13.2	Mira	252	M
R Fornacis	02	29.3	-26	06	7.5-13.0	Mira	388	N
η Geminorum	06	14.9	+22	30	3.1- 4.2	Semi-reg.	±233	M
ζ Geminorum	07	04.1	+20	34	3.7- 4.1	Cepheid	10.2	F-G
R Geminorum	07	07.4	+22	42	6.0-14.0	Mira	370	S
U Geminorum	07	55.1	+22	00	8.2-14.9	Dwarf nova	±103	M+WD
S Gruis	22	26.1	-48	26	6.0-15.0	Mira	401	M
α Herculis	17	14.6	+14	23	3.0- 4.0	Semi-reg.	±100	M
S Herculis	17	17.3	+35	06	4.6- 5.3	Beta Lyrae	2.1	B+B
U Herculis	16	25.8	+18	54	6.5-13.4	Mira	406	M
R Hydrae	13	29.7	-23	17	4.0-10.0	Mira	390	M
U Hydrae	10	37.6	-13	23	4.8- 5.8	Semi-reg.	450	N
VW Hydri	04	09.1	-71	18	8.4-14.4	Dwarf nova	100	M
R Leonis	09	47.6	+11	25	4.4-11.3	Mira	312	M
R Leonis Min.	09	45.6	+34	31	6.3-13.2	Mira	372	M
R Leporis	04	59.6	-14	48	5.5-11.7	Mira	432	N
δ Librae	15	01.1	-08	31	4.9- 5.9	Algol	2.3	B
Y Librae	15	11.7	-06	01	7.6-14.7	Mira	275	M
R Lyncis	07	01.3	+55	20	7.2-14.5	Mira	379	S
β Lyrae	18	50.1	+33	22	3.3- 4.3	Beta Lyrae	12.9	B+A
R Lyrae	18	55.3	+43	57	3.9- 5.0	Semi-reg.	46	M
RR Lyrae	19	25.5	+42	47	7.1- 8.1	RR Lyrae	0.6	A-F
U Microscopii	20	29.2	-40	25	7.0-14.4	Mira	334	M
U Monocerotis	07	30.8	-09	47	6.1- 8.1	RV Tauri	92	F-K
S Monocerotis	06	41.0	+09	54	4 - 5?	Irregular	-	07
T Normae	15	44.1	-54	59	6.2-13.6	Mira	243	M
R Octantis	05	26.1	-86	23	6.4-13.2	Mira	406	M
S Octantis	18	08.7	-86	48	7.3-14.0	Mira	259	M
RS Ophiuchi	17	50.2	-06	43	5.3-12.3	Recurrent nova	-	O+M
X Ophiuchi	18	38.3	+08	50	5.9- 9.2	Mira	334	M+K
α Orionis	05	55.2	+07	24	0.1- 0.9	Semi-reg.	±2110	M
U Orionis	05	55.8	+20	10	4.8-12.6	Mira	372	M
W Orionis	05	05.4	+01	11	5.9- 7.7	Semi-reg.	212	N
κ Pavonis	18	56.9	-67	14	3.9- 4.7	W Virginis	9.1	F
S Pavonis	19	55.2	-59	12	6.6-10.4	Semi-reg.	386	M
β Pegasi	23	03.8	+28	05	2.3- 2.8	Semi-reg.	38	M
R Pegasi	23	06.8	+10	33	6.9-13.8	Mira	378	M
β Persei	03	08.2	+40	57	2.2- 3.4	Algol	2.9	B+G
ο Persei	03	05.2	+38	50	3 - 4	Semi-reg.	33to55	M
X Persei	03	55.4	+31	03	6 - 7	Irreg.(X-ray)	-	09.5
ζ Phoenicis	01	08.4	-55	15	3.9- 4.4	Algol	1.7	B+B
R Pictoris	04	46.2	-49	15	6.7-10.0	Semi-reg.	164	M
L ² Puppis	07	13.5	-44	39	2.6- 6.2	Semi-reg.	140	M
T Pyxidis	09	04.7	-32	23	6.3-14.0	Recurrent nova	-	Q
U Sagittae	19	18.8	+19	37	6.6- 9.2	Algol	3.4	B-K
WZ Sagittae	20	07.6	+17	42	7.0-15.5	Recurrent nova	-	Q
RR Sagittarii	19	55.9	-29	11	5.6-14.0	Mira	335	M
RT Scorpii	17	03.5	-36	55	7.0-16.0	Mira	449	M
RY Sagittarii	19	16.5	-33	31	6.0-15	R Coronae	-	Gp
S Sculptoris	00	15.4	-32	03	5.5-13.6	Mira	365	M
R Scuti	18	47.5	-05	42	4.4- 8.2	RV Tauri	140	G-K
R Serpentis	15	50.7	+15	08	5.1-14.4	Mira	356	M
S Serpentis	15	21.7	+14	19	7.0-14.1	Mira	369	M
Tauri	04	00.7	+12	29	3.3- 3.8	Algol	3.9	B+A

T Tauri	04	22.0	+19	32	8.4-13.5	T Tauri	—	G-K
SU Tauri	05	49.1	+19	04	9.1-16.0	R Coronae	—	Gp
R Trianguli	02	37.0	+34	16	5.4-12.6	Mira	266	M
R Ursæ Major.	10	44.6	+58	47	6.7-13.4	Mira	302	M
T Ursæ Major.	12	36.4	+59	29	6.6-13.4	Mira	256	M
U Ursæ Minor.	14	17.3	+66	48	7.4-12.7	Mira	326	M
X Virginis	12	01.9	+09	04	7.3-11.2	?	—	F
SS Virginis	12	25.3	+00	48	6.0- 9.6	Mira	355	N
R Virginis	12	38.5	+06	59	6.0-12.1	Mira	146	M
S Virginis	13	33.0	—07	12	6.3-13.2	Mira	377	M
R Vulpeculae	21	04.4	+23	49	7.0-14.3	Mira	136	M
Z Vulpeculae	19	21.7	+25	34	7.4- 9.2	Algol	2.5	B+A

Variable Star Maxima for 1989

The following dates for the maxima of pulsating stars are no more than approximations, as it is impossible to be precise, but the list may be of help to enthusiastic variable star observers.

JANUARY	6 R Leo	JULY	OCTOBER
1 R Ret	7 W Cyg	2 W Cet	2 T Eri
2 W CrB, RCVn,	11 V Boö	6 R Lep	6 T Aqr, R Ret
R Peg	12 S Ser	8 R UMa	8 RU Her
4 X Cnc, R Com	13 SV And	13 T Cas, R Aql	9 V Cas, R Car
7 S Peg	19 S Boö, Z Peg	15 R Hya	15 R Aqr
9 R Tau, R Crv	20 R And	18 X Cnc	18 Z Oph
10 U Cet	24 V Gem	19 R Dra	19 S Her, S Car
11 T Cam, RU Lib	27 R Psc	24 T And	20 S UMa
15 RT Aql	28 R Boö	25 RT Cyg	26 X Oph
16 RT Cyg			27 Mira Ceti, R Lyn
24 X Cam	MAY	AUGUST	28 W Cnc
28 CN Cyg	1 RR Lib	2 R CMi	31 V CMi, RS Her,
	4 T Hya	7 V Oph	V Peg
FEBRUARY	5 R Oct, U Vir	11 W Cyg	NOVEMBER
1 U Ser	6 R Cen	12 T Dra	6 U Her
6 V Cnc	7 U Per	15 CN Cyg	8 X Cam
21 W Her	10 W Lyr	17 R Vir, S Vir,	10 ST And
22 R Cyg, V Cas	12 W Lyn	R Vul, R Peg	15 S CrB
27 TW Peg	13 U Ari, U Aur	18 R Cet	16 R Cnc
	14 R Ser	22 R Cam, T Nor	21 S UMi
MARCH	17 U UMi	23 RY Oph	22 Chi Cyg, S Peg
5 R Cet	18 R Aur	25 R Gem	24 RS Vir, W Lyr
8 S UMa	21 T UMa	28 W CrB	28 W And, U Vir,
14 Z UMa	22 S Lac	30 T Col	W Her
15 Y Lib	23 T Cep, S Car		29 W Cas
18 T Aqr	26 S Ori	SEPTEMBER	DECEMBER
20 S Scl	27 R Sgr	2 U Cet	5 U Ori
24 R Tri, R Vir		7 S Cet	7 R Ari, R Boö
25 RS Her	JUNE	9 X Gem	11 S Hya
26 RY Oph	3 R Ari	11 T Her	15 R Tri, W Cyg
28 S Cam	4 S Cep	13 Z Cyg	16 Y Lib
29 S Hya	6 X Hya	26 Z UMa	24 RZ Peg
30 T Her	8 RR Aql	27 U Ser, R Del	25 V Boö
	9 R Oph	29 SS Oph	29 R Hor
APRIL	17 R Nor	30 U Cyg	31 R Vul
1 W Peg	19 V CrB		
2 SS Oph	21 R LMi		
3 R Vul	28 Y Dra		

Some Interesting Double Stars

We are very grateful to Robert Argyle for this revised list of double stars, which is up to date.

<i>Name</i>	<i>Magnitudes</i>	<i>Separation"</i>	<i>Position angle °</i>	<i>Remarks</i>
Gamma Andromedæ	3.0, 5.0	9.4	064	Yellow, blue. B is again double (0".5) but needs larger telescope.
Zeta Aquarii	4.4, 4.6	1.8	217	Becoming more difficult.
Gamma Arietis	4.2, 4.4	7.8	000	Very easy.
Theta Aurigæ	2.7, 7.2	3.5	313	Stiff test for 3"0G.
Delta Boötis	3.2, 7.4	105	079	Fixed.
Epsilon Boötis	3.0, 6.3	2.8	335	Yellow, blue. Fine pair.
Kappa Boötis	5.1, 7.2	13.6	237	Easy.
Zeta Cancri	5.6, 6.1	5.6	085	Again double.
Iota Cancri	4.4, 6.5	31	307	Easy. Yellow, blue.
Alpha Canum Ven.	3.2, 5.7	19.6	228	Easy. Yellowish, bluish.
Alpha Capricorni	3.3, 4.2	376	291	Naked-eye pair.
Eta Cassiopeiæ	3.7, 7.4	12.2	310	Easy. Creamy, bluish.
Beta Cephei	3.3, 8.0	14	250	Easy with a 3 in.
Delta Cephei	var, 7.5	41	192	Very easy.
Alpha Centauri	0.0, 1.7	21.7	212	Very easy. Binary, period 80 years.
Xi Cephei	4.7, 6.5	6.3	270	Reasonably easy.
Gamma Ceti	3.7, 6.2	2.9	294	Not too easy.
Alpha Circini	3.4, 8.8	15.7	230	PA slowly decreasing.
Zeta Coronæ Bor.	4.0, 4.9	6.3	305	PA slowly increasing.
Delta Corvi	3.0, 8.5	24	214	Easy with 3 in.
Alpha Crucis	1.6, 2.1	4.7	114	Third star in low-power field.
Gamma Crucis	1.6, 6.7	111	212	Wide optical pair.
Beta Cygni	3.0, 5.3	34.3	055	Glorious. Yellow, blue.
61 Cygni	5.3, 5.9	29	147	Slowly widening. (Add .5)
Gamma Delphini	4.0, 5.0	9.6	268	Easy. Yellow, greenish.
Nu Draconis	4.6, 4.6	62	312	Naked-eye pair.
Alpha Geminorum	2.0, 2.8	2.6	085	Becoming easier.
Delta Geminorum	3.2, 8.2	6.5	120	Not too easy.
Alpha Herculis	var, 6.1	4.6	106	Red, green.
Delta Herculis	3.0, 7.5	8.6	262	Optical pair.
Zeta Herculis	3.0, 6.5	1.5	110	Fine, rapid binary (34y)
Gamma Leonis	2.6, 3.8	4.4	123	Binary; 619 years.
Alpha Lyræ	0.0, 10.5	73	180	Optical. B is faint.
Epsilon Lyræ	4.6, 6.3	2.6	356	Quadruple. Both pairs.
	4.9, 5.2	2.2	093	separable with 3 in.
Zeta Lyræ	4.2, 5.5	44	149	Fixed. Easy double.

(continued overleaf)

<i>Name</i>	<i>Magnitudes</i>	<i>Separation "</i>	<i>Position angle °</i>	<i>Remarks</i>
Beta Orionis	0.1, 6.7	9.5	205	Can be split with 3 in.
Iota Orionis	3.2, 7.3	11.8	141	Enmeshed in nebulosity.
Theta Orionis	6.8, 7.9	8.7	032	Trapezium in M. 42.
	6.8, 5.4	13.4	241	
Sigma Orionis	4.0, 10.3	11.1	236	Quadruple. C is rather faint in small apertures.
	6.8, 8.0	30.1	231	
Zeta Orionis	2.0, 4.2	2.4	162	Can be split with 3 in.
Eta Persei	4.0, 8.5	28.5	300	Yellow, bluish.
Beta Phœnicis	4.1, 4.1	1.1	319	Slowly closing.
Beta Piscis Austr.	4.4, 7.9	30.4	172	Optical pair. Fixed.
Alpha Piscium	4.3, 5.3	1.9	283	Binary; 720 years.
Kappa Puppis	4.5, 4.6	9.8	318	Again double.
Alpha Scorpii	0.9, 6.8	3.0	275	Red, green.
Nu Scorpii	4.2, 6.5	42	336	Both again double.
Theta Serpentis	4.1, 4.1	22.3	103	Very easy.
Alpha Tauri	0.8, 11.2	131	032	Wide, but B very faint in small telescopes.
Beta Tucanæ	4.5, 4.5	27.1	170	Both again double.
Zeta Ursæ Majoris	2.1, 4.2	14.4	151	Very easy. Naked-eye pair with Alcor.
Alpha Ursæ Minoris	2.0, 9.0	18.3	217	Can be seen with 3 in.
Gamma Virginis	3.6, 3.7	3.5	292	Binary; 171 years. Closing.
Theta Virginis	4.0, 9.0	7.1	343	Not too easy.
Gamma Volantis	3.9, 5.8	13.8	299	Very slow binary.

Some Interesting Nebulæ and Clusters

<i>Object</i>	<i>R.A.</i>		<i>Dec.</i>	<i>Remarks</i>
	<i>h</i>	<i>m</i>	<i>°</i>	
M.31 Andromedæ	00	40.7	+41	05 Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41.3	+61	36 Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31.8	+30	28 Spiral. Difficult with small apertures.
H.VI 33-4 Persei	02	18.3	+56	59 Double cluster; Sword-handle.
Δ142 Doradûs	05	39.1	-69	09 Looped nebula round 30 Doradûs. Naked-eye. In Large Cloud of Magellan.
M.1 Tauri	05	32.3	+22	00 Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33.4	-05	24 Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06.5	+24	21 Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30.7	+04	53 Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45.5	-20	42 Open cluster, just visible to naked eye.
M.47 Puppis	07	34.3	-14	22 Mag. 5.2. Loose cluster.
H.IV 64 Puppis	07	39.6	-18	05 Bright planetary in rich neighbourhood.
M.46 Puppis	07	39.5	-14	42 Open cluster.
M.44 Cancri	08	38	+20	07 Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12.6	+55	13 Owl Nebula, diameter 3'. Planetary.
Kappa Crucis	12	50.7	-60	05 "Jewel Box"; open cluster, with stars of contrasting colours.
M.3 Can. Ven.	13	40.6	+28	34 Bright globular.
Omega Centauri	13	23.7	-47	03 Finest of all globulars. Easy with naked eye.
M.80 Scorpïi	16	14.9	-22	53 Globular, between Antares and Beta Scorpionis.
M.4 Scorpïi	16	21.5	-26	26 Open cluster close to Antares.
M.13 Herculis	16	40	+36	31 Globular. Just visible to naked eye.
M.92 Herculis	17	16.1	+43	11 Globular. Between Iota and Eta Herculis.
M.6 Scorpïi	17	36.8	-32	11 Open cluster; naked-eye.
M.7 Scorpïi	17	50.6	-34	48 Very bright open cluster; naked eye.
M.23 Sagittarii	17	54.8	-19	01 Open cluster nearly 50' in diameter.
H.IV 37 Draconis	17	58.6	+66	38 Bright Planetary.
M.8 Sagittarii	18	01.4	-24	23 Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10.9	+06	50 Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18.8	-16	12 Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49.0	-06	19 Wild Duck. Bright open cluster.
M.57 Lyræ	18	52.6	+32	59 Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58.1	+22	37 Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02.1	-11	31 Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28.3	+12	01 Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31.0	+48	17 Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

Our Contributors

Dr Gilbert Fielder is one of the world's leading authorities with regard to the Moon. He was for many years lecturing and researching at the University of Lancaster, and now continues his researches from his home in Austwick, Lancashire. He has written many popular books as well as technical contributions.

Dr Peter Cattermole, of the Department of Geology at Sheffield University, is one of the few British Principal Scientific Investigators for NASA. He has been concerned largely with the volcanoes of Mars and Venus. He has written many books, both popular and technical.

Dr David Allen, of the Siding Spring Observatory in New South Wales, needs no introduction to *Yearbook* readers. He has been our most regular contributor over the years; suffice to say that he continues his researches, largely in the realm of infra-red astronomy, as well as with his writing and broadcasting.

Professor Arnold Wolfendale, F.R.S., is Head of the Department of Physics at Durham University. He has spent many years researching in cosmic rays both observationally and, latterly, theoretically, endeavouring to discover the origin of these enigmatic particles.

Dr Ian McLean is Principal Scientific Officer at the Joint Astronomy Centre in Hilo, Hawaii, which is operated by the Royal Observatory Edinburgh. He is Project Scientist for the UKIRT Infra-Red Camera (IRCAM).

Kieron Leech, of the School of Mathematical Sciences at Queen Mary College, University of London, is concerned largely with infra-red studies, and is a member of the combined QMC/RGO team working upon the results obtained with the successful IRAS satellite.

Dr Paul Murdin is one of the world's leading astrophysicists, and until recently was in charge of the British telescopes at La Palma. He has been at the Royal Greenwich Observatory, Herstmonceux, but with the impending removal of the RGO he will be moving to the new location at Cambridge.

There is now a permanent public exhibition at the Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex. It is open on weekdays between 2 and 5.30 p.m., and on Saturdays, Sundays and public holidays from 10.30 a.m. to 5.30 p.m. The Exhibition covers the fields of modern astronomy, the development of telescopes, the history of the Observatory and of the Castle. There is a tea room (June-September), a souvenir shop, and free parking.

The William Herschel Society maintains the museum now established at 19 New King Street, Bath – the only surviving Herschel house. It also undertakes activities of various kinds. New members would be welcome; those interested are asked to contact Dr L. Hilliard at 2 Lambridge, London Road, Bath.

Astronomical Societies in Great Britain

The advantages of joining an astronomical society are obvious enough. This list is up to date at time of going to press.

British Astronomical Association

Secretary: E. Watson-Jones, Burlington House, Piccadilly, London. W1

Meetings: Lecture Hall of Scientific Societies, Civil Service Commission Building, 23 Savile Row, London W1. Last Wednesday each month (Oct.-June). 1700 hrs and some Saturday afternoons.

Association for Astronomy Education

Secretary: Capt. P. Richards-Jones, Crosstrees, 9 Old Oak Avenue, Chipstead, Coulsdon. Surrey.

Astronomical Society of Wales

Secretary: G. E. Evans, 121a Penycae Road, Port Talbot, West Glamorgan.

Federation of Astronomical Societies

Secretary: D. Powell, 1 Tal-y-bont Road, Ely, Cardiff, South Wales.

Irish Astronomical Association

Treasurer: Gillian Flannagan, 83 Kincora Avenue, Clontarf, Dublin 3.

Meetings: As arranged, fortnightly. Sept-April.

Junior Astronomical Society

Secretary: M. Ratcliffe, 36 Fairway, Keyworth, Nottingham.

Meetings: Central Library, Theobalds Road, London WC1. Last Saturday Jan.. April, July, Oct. 2.30 p.m.

Junior Astronomical Society of Ireland

Secretary: K. Nolan, 5 St Patrick's Crescent, Rathcoole, Co. Dublin.

Meetings: The Royal Dublin Society, Ballsbridge, Dublin 4. Monthly

Aberdeen and District Astronomical Society

Secretary: Stephen Graham, 25 Davidson Place, Northfield, Aberdeen.

Meetings: Robert Gordon's Institute of Technology, St Andrew's Street, Aberdeen. Friday 7.30 p.m.

Altrincham and District Astronomical Society

Secretary: Colin Henshaw, 10 Delamore Road, Gatley, Cheadle, Cheshire.

Meetings: Public Library, Timperley. 1st Friday of each month, 7.30 p.m.

Astra Astronomy Section

Secretary: Ian Downie, 151 Sword Street, Glasgow, G31

Meetings: Public Library, Airdrie. Weekly.

Aylesbury Astronomical Society

Secretary: N. Neale, 9 Elm Close, Butler's Cross, Aylesbury.

Bassettlaw Astronomical Society

Secretary: P. R. Stanley, 28 Festival Avenue, Harworth, nr. Doncaster.

Meetings: Farr, Community Hall, Chapel Walk, Westgate, Worksop, Notts. Tuesday fortnightly, 7.30 p.m.

Batley & Spensborough Astronomical Society

Secretary: A. Burrows, 4 Norwood Drive, Batley, West Yorks.

Meetings: Milner K. Ford Observatory, Wilton Park, Batley. Every Thursday, 7.30 p.m.

Bedford Astronomical Society

Secretary: D. Eagle, 24 Copthorne Close, Oakley, Bedford.

Meetings: Bedford school, Burnaby Rd, Bedford. Last Tuesday each month.

Bideford Astronomical Society

Secretary: David Lemon, 5 Capern Road, Bideford, N. Devon.

Meetings: Torridge Inn, Torridge Hill. Last Monday in Month Sept.-May. 7.15 p.m.

Bingham & Brookes Space Organization

Secretary: N. Bingham, 15 Hickmore's Lane, Lindfield, W. Sussex.

Birmingham Astronomical Society

Secretary: P. Truelove, 58 Taylor Road, King's Heath, Birmingham.

Meetings: Room 261, University of Aston, last Tuesday each month, Sept. to May.

Blackpool & District Astronomical Society

Secretary: J. L. Crossley, 24 Fernleigh Close, Bispham, Blackpool, Lancs.

Bolton Astronomical Society

Secretary: Peter Miskiw, 9 Hedley Street, Bolton.

Border Astronomical Society

Secretary: David Pettit, 14 Shap Grove, Carlisle, Cumbria.

Boston Astronomers

Secretary: B. Tongue, South View, Fen Road, Stickford, Boston.

Meetings: Details from the Secretary.

- Bradford Astronomical Society**
Secretary: B. Jones, 28 High House Avenue, Bolton, Bradford, W. Yorks.
Meetings: Eccleshill Library, Bradford 2. Monday fortnightly (with occasional variations).
- Braintree, Halstead & District Astronomical Society**
Secretary: Heather Reeder, The Knoll, St Peters in the Field, Braintree, Essex.
Meetings: St Peter's Church Hall, St Peter's Road, Braintree, Essex. 3rd Thursday each month, 8 p.m.
- Bridgend Amateur Astronomical Society**
Secretary: J. M. Pugsley, 32 Hoel Fawr, Broadlands, North Cornelly, Bridgend.
Meetings: G.P. Room, Recreation Centre, Bridgend, 1st and 3rd Friday monthly, 7.30 p.m.
- Bridgwater Astronomical Society**
Secretary: W. L. Buckland, 104 Polden Street, Bridgwater, Somerset.
Meetings: Room D10, Bridgwater College, Bath Road Centre, Bridgwater. 2nd Wednesday each month, Sept–June.
- Brighton Astronomical Society**
Secretary: Mrs B. C. Smith, Flat 2, 23 Albany Villas, Hove, Sussex, BN3 2RS.
Meetings: Preston Tennis Club, Preston Drive, Brighton. Weekly, Tuesdays.
- Bristol Astronomical Society**
Secretary: Y. A. Sage, 33 Mackie Avenue, Filton, Bristol.
Meetings: Royal Fort (Rm G44), Bristol University. Every Friday each month, Sept.–May. Fortnightly, June–August.
- Cambridge Astronomical Association**
Secretary: Mrs Carol Madden, 23 Scotsdowne Road, Trumpington, Cambridge.
Meetings: The Village College, Comberton, Cambridge. 2nd Mon. each month, 19.30 hrs.
- Cardiff Astronomical Society**
Secretary: D. W. S. Powell, 1 Tal-y-Bont Road, Ely, Cardiff.
Meeting Place: Room 230, Dept. Law, University College, Museum Avenue, Cardiff.
 Alternate Thursdays, 8 p.m.
- Chelmsford and District Astronomical Society**
Secretary: Miss C. C. Puddick, 6 Walpole Walk, Rayleigh, Essex.
Meetings: 7.45 p.m. Sandon House School, Sandon Near Chelmsford, 2nd and last Monday of month.
- Chelmsley Astronomical Society**
Secretary: J. Williams, 100 Stanway Road, Shirley, Solihull, West Midlands
Meetings: Chelmsley Wood Library. Last Thursday in month.
- Chester Astronomical Society**
Secretary: Mrs S. Brooks, 39 Halton Road, Great Sutton, South Wirral.
Meetings: Southview Community Centre, Southview Road, Chester. Last Monday each month except Aug. and Dec., 7.30 p.m.
- Chester Society of Natural Science Literature and Art**
Secretary: Paul Braid, 'White Wing', 38 Bryn Avenue, Old Colwyn, Colwyn Bay, Clwyd.
Meetings: Grosvenor Museum, Chester. Fortnightly.
- Chesterfield Astronomical Society**
Secretary: P. Lisewski, 148 Old Hall Road, Brampton Chesterfield.
Meetings: Barnet Observatory, Newbold. Each Friday.
- Clacton & District Astronomical Society**
Secretary: C. L. Haskell, 105 London Road, Clacton-on-Sea, Essex.
- Cleethorpes & District Astronomical Society**
Secretary: Peter Rea, 1 Rosina Grove North, Grimsby.
Meetings: Beacon Hill Observatory, Cleethorpes. 1st Wednesday each month.
- Cleveland Astronomical Society**
Secretary: John Nicol, 44 Bradbury Road, Norton, Stockton-on-Tees, Cleveland
Meetings: Monthly.
- Colchester Amateur Astronomers**
Secretary: F. Kelly, 'Middleton', Church Road, Elmstead Market, Colchester, Essex.
Meetings: William Loveless Hall, High Street, Wivenhoe. Friday evenings. Fortnightly.
- Cotswold Astronomical Society**
Secretary: A. Ireland, 8 Merestone Drive, The Park, Cheltenham, Gloucs.
Meetings: Fortnightly in Cheltenham or Gloucester
- Coventry & Warwicks Astronomical Society**
Secretary: Alan Hancocks, 33 Gainford Rise, Binley, Coventry.
Meetings: Coventry Technical College. 1st Friday each month, Sept–June.
- Crawley Astronomical Society**
Secretary: G. Cowley, 67 Climpixy Road, Ifield, Crawley, Sussex.
Meetings: Crawley College of Further Education. Monthly Oct.–June.
- Crayford Manor House Astronomical Society**
Secretary: R. H. Chambers, Manor House Centre, Crayford, Kent.
Meetings: Manor House Centre, Crayford. Monthly during term-time.

Croydon Astronomical Society

Secretary: J. B. Haydon, 62 Sanderstead Rd, South Croydon, Surrey.

Meetings: Lanfranc High School, Mitcham Rd., Croydon. Alternate Fridays, 7.45 p.m.

Dartington Astronomical Society

Secretary: Mrs Iris Alison, 'Wayfaring', Cott Lane, Dartington, Totnes, Devon.

Meetings: Meeting Room, Shinnars Bridge Centre, Dartington, 3rd Wed. each month at 8 p.m. Observation all other Wed. evenings (weather permitting) on Foxhole clock tower.

Derby & District Astronomical Society

Secretary: Jane D. Kirk, 7 Cromwell Avenue, Findern, Derby.

Meetings: At home of Secretary. First and third Friday each month, 7.30 p.m.

Doncaster Astronomical Society

Secretary: J. A. Day, 297 Lonsdale Avenue, Intake, Doncaster.

Meetings: Fridays, weekly.

Dundee Astronomical Society

Secretary: G. Young, 37 Polepark Road, Dundee, Angus.

Meetings: Mills Observatory, Balgay Park, Dundee. First Friday each month, 7.30 p.m. Sept.-April.

Easington and District Astronomical Society

Secretary: T. Bradley, 52 Jameson Road, Hartlepool, Co. Durham.

Meetings: Easington Comprehensive School, Easington Colliery. Every third Thursday throughout the year, 7.30 p.m.

Eastbourne Astronomical Society

Secretary: D. C. Gates, 27 Highview Close, Windmill Hill, Hurstmonceux, East Sussex.

Meetings: St. Aiden's Church Hall, Seaside, Eastbourne. Monthly (except July and August).

East Lancashire Astronomical Society

Secretary: D. Chadwick, 16 Worston Lane, Great Harwood, Blackburn, BB6 7TH.

Meetings: As arranged. Monthly.

Astronomical Society of Edinburgh

Secretary: R. G. Fenoulhet, 7 Greenend Gardens, Edinburgh, EH17 7QB.

Meetings: City Observatory, Calton Hill, Edinburgh. Monthly.

Edinburgh University Astronomical Society

Secretary: c/o Dept. of Astronomy, Royal Observatory, Blackford Hill, Edinburgh.

Ewell Astronomical Society

Secretary: Ron W. Johnson, 19 Elm Way, Ewell, Surrey.

Meetings: 1st Friday of each month.

Exeter Astronomical Society

Secretary: Miss J. Corey, 5 Egham Avenue, Topsham Road, Exeter.

Meetings: The Meeting Room Wynards, Magdalen Street, Exeter. 1st Thursday of month.

Farnham Astronomical Society

Secretary: Laurence Anslow, 14 Wellington Lane, Farnham, Surrey.

Meetings: Church House, Union Road, Farnham. 2nd Monday each month, 7.45 p.m.

Fitzharry's Astronomical Society (Oxford & District)

Secretary: J. Fathers, 94 Frelands Road, Oxford.

Meetings: Monthly, Sept.-May.

Furness Astronomical Society

Secretary: C Taylor, 37 Lancashire Rd. Milbom, Cumbria.

Meetings: Members' homes. 1st Saturday in month, 7.30 p.m. No August meeting.

Fylde Astronomical Society

Secretary: 28 Belvedere Road, Thornton, Lancs.

Meetings: Stanley Hall, Rossendale Ave. South. 1st Wednesday each month.

Astronomical Society of Glasgow

Secretary: Malcolm Kennedy, 32 Cedar Road, Cumbernauld, Glasgow.

Meetings: University of Strathclyde, George St, Glasgow. 3rd Thursday each month, Sept.-April.

Grimsby Astronomical Society

Secretary: R. Williams, 14 Richmond Close, Grimsby. South Humberside.

Meetings: Secretary's home. 2nd Thursday each month. 7.30 p.m.

Guernsey: La Société Guernesiaise Astronomy Section

Secretary: David Le Conte, Belle Etoile, Rue de Hamel, Castel, Guernsey.

Meetings: Monthly.

Guildford Association Society

Secretary: Mrs Joan Prosser, 115 Farnham Road, Guildford, Surrey.

Meetings: Guildford Institute, Ward Street, Guildford. 1st Thursday each month. Sept.-June, 7.30 p.m.

Gwynedd Astronomical Society

Secretary: P. J. Curtis, Ael-y-bryn, Malltraeth St. Newborough, Anglesey, Gwynedd.

Meetings: Physics Lecture Room, Bangor University. 1st Thursday each month, 7.30 p.m.

The Hampshire Astronomical Group

Secretary: Miss J. Hutso, 33 Mapletree Avenue, Horndean, Hants.

Meetings: The Group Observatory.

Astronomical Society of Haringey

Secretary: Wally Baker, 58 Stirling Road, Wood Green, London, N22.

Meetings: The Hall of the Good Shepherd, Berwick Road, Wood Green. Wednesday, each month. 8 p.m.

Harrogate Astronomical Society

Secretary: J. N. Eagin, 23 Crowberry Drive, Harrogate, North Yorks.

Hebden Bridge Literary & Scientific Society, Astronomical Section

Secretary: F. Parker, 48 Caldene Avenue, Mytholmroyd, Hebden Bridge, West Yorkshire.

Herschel Astronomical Society

Secretary: Dr. A. K. Welch, Tumbleweed, The Common, Winchmore-Hill, Amersham, Bucks.

Meetings: Trinity Church Annex, Windsor Road, Slough. Fortnightly, Friday.

Howards Astronomy Club

Secretary: H. Ilett, 22 St Georges Avenue, Warblington, Havant, Hants

Meetings: To be notified.

Huddersfield Astronomical and Philosophical Society

Secretary (Assistant): M. Armitage, 37 Frederick Street, Crossland Moor, Huddersfield.

Meetings: 4A Railway Street, Huddersfield. Every Friday, 7.30 p.m.

Hull and East Riding Astronomical Society

Secretary: J. I. Booth, 3 Lynngarth Ave., Cottingham, North Humberside.

Meetings: Ferens Recreation Centre, Chanterlands Avenue Hull. 1st Friday each month, Oct.-April, 7.30 p.m.

Ilkeston & District Astronomical Society

Secretary: Bernard Wheeldon, 89 Heanor road, Ilkeston.

Meetings: Erewash Museum, Ilkeston. 2nd Tuesday monthly.

Ipswich, Orwell Astronomical Society

Secretary: R. Gooding, 168 Ashcroft Road, Ipswich.

Meetings: Orwell Park Observatory, Nacton, Ipswich. Wednesdays 8 p.m.

Isle of Wight Astronomical Society

Secretary: J. W. Feakins, 1 Hilltop Cottages, High Street, Freshwater, Isle of Wight.

Meetings: Unitarian Church Hall, Newport, Isle of Wight. Monthly.

Keele Astronomical Society

Secretary: Miss Caterina Callus, University of Keele, Keele, Staffs.

Meetings: As arranged during term time.

King's Lynn Amateur Astronomical Association

Secretary: P. Twynman, 17 Poplar Avenue, R.A.F. Marham, King's Lynn.

Meetings: As arranged.

Lancaster and Morecambe Astronomical Society

Secretary: Miss E. Haygarth, 27 Coulston Road, Bowerham, Lancaster.

Meetings: Midland Hotel, Morecambe. 1st Wednesday each month except January. 7.30 p.m.

Lancaster University Astronomical Society

Secretary: c/o. Students Union, Alexandra Square, University of Lancaster.

Meetings: As arranged.

Laymans Astronomical Society

Secretary: John Evans, 10 Arkwright Walk, The Meadows, Nottingham.

Meetings: The Popular, Bath Street, Ilkeston, Derbyshire. Monthly.

Leeds Astronomical Society

Secretary: A. J. Higgins, 23 Montagu Place, Leeds, LS8 2RQ.

Meetings: Lecture Room, City Museum Library, The Headrow, Leeds.

Leicester Astronomical Society

Secretary: Dereck Brown, 64 Grange Drive, Glen Parva, Leicester.

Meetings: Judgemeadow Community College, Marydene Drive, Evington, Leicester. 2nd and 4th Tuesdays each month, 7.30 p.m.

Lincoln Astronomical Society

Secretary: T. Hopkinson, 121 Longdales Road, Lincoln.

Meetings: The Lecture Hall, off Westcliffe Street, Lincoln. 1st Tuesday each month.

Liverpool Astronomical Society

Secretary: Martin Sugget

Meetings: City Museum, Liverpool. Monthly.

Loughton Astronomical Society

Secretary: J. P. Ringwood c/o Loughton, Astronomical Society

Meetings: Loughton Hall, Rectory Lane, Loughton, Essex. Thursdays 8 p.m.

Lowestoft and Great Yarmouth Regional Astronomers (LYRA) Society

Secretary: S. Briggs, 65 Stubbs Wood, Gunton Park, Lowestoft, Suffolk.

Meetings: Committee Room No. 30, Lowestoft College of F.E., St Peter's Street, Lowestoft, 3rd Thursday, Sept.-May (Weather permitting on Corton Cliff site), 7.15 p.m.

Luton & District Astronomical Society

Secretary: D. Childs, 6 Greenways, Stopsley, Luton.

Meetings: Luton College of Higher Education, Park Square, Luton. Second and last Friday each month, 7.30 p.m.

Lytham St. Annes Astronomical Association

Secretary: K. J. Porter, 141 Blackpool Road, Ansdell, Lytham St. Annes, Lancs.

Meetings: College of Further Education, Clifton Drive S., Lytham St. Annes. 2nd Wednesday monthly Oct.–June.

Maidenhead Astronomical Society

Secretary: T. V. Haymes, 58 Portlock Road, Maidenhead.

Meetings: Library. Monthly (except July and August. 3rd Tuesday.)

Manchester Astronomical Society

Secretary: J. H. Davidson, Godlee Observatory, UMIST, Sackville Street, Manchester 1.

Meetings: At the Observatory, Thursdays, 7.30–9 p.m.

Mansfield and Sutton Astronomical Society

Secretary: G. W. Shepherd, Sherwood Observatory, Coxmoor Road, Sutton-in-Ashfield, Notts.

Meetings: Sherwood Observatory, Oakmoor Road. Last Tuesday each month.

Mexborough and Swinton Astronomical Society

Secretary: Mark R. Benton, 61 The Lea, Swinton, Mexborough, Yorks.

Meetings: Methodist Hall, Piccadilly Road, Swinton, Near Mexborough. Thursdays, 7 p.m.

Mid-Kent Astronomical Society

Secretary: Brian A. van de Peep, 11 Berber Road, Strood, Rochester, Kent.

Meetings: Medway Teachers Centre, Vicarage Road, Strood, Rochester, Kent, last Friday in month. Mid Kent College, Horsted, 2nd Friday in month.

Mid-Sussex Astronomical Society

Secretary: Dr. L. K. Brundle, 63 Pasture Hill Road, Haywards Heath, West Sussex.

Meetings: Haywards Heath College, Harlands Road, Haywards Heath. Monthly, Wednesdays 7.30 p.m.

Milton Keynes Astronomical Society

Secretary: The Secretary, Milton Keynes Astronomical Society, Bradwell Abbey Field Centre, Bradwell, Milton Keynes, MK1 39AP.

Meetings: Alternate Tuesdays.

Newbury Amateur Astronomical Society

Secretary: Mrs. A. Davies, 11 Sedgfield Road, Greenham, Newbury, Berks.

Meetings: United Reform Church Hall, Cromwell Road, Newbury. Last Friday of month, Aug.–May.

Newcastle-on-Tyne Astronomical Society

Secretary: C. E. Willits, 24 Acomb Avenue, Seaton Delaval, Tyne and Wear.

Meetings: Zoology Lecture Theatre, Newcastle University. Monthly.

Newtonian Observatory Astronomical Society

Secretary: Miss P. E. Randle, 62 Northcott Road, Worthing, Sussex.

Meetings: Adult Education Centre, Union Place, Worthing. 1st Wednesday each month except Aug. 7.30 p.m.

North Aston Space & Astronomical Club

Secretary: W. R. Chadburn, 14 Oakdale Road, North Aston, Sheffield.

Meetings: To be notified

North Clwyd Astronomical Society

Secretary: D. S. Owen, 2 Lon Kinnel, Pensarn, Abergele, Clwyd.

North Devon Astronomical Society

Secretary: D. Lemon, 5 Capern Rd, Bideford.

Meetings: Pilton Community College, Chaddiford Lane, Barnstaple. 1st Wednesday each month, Sept.–May.

North Dorset Astronomical Society

Secretary: J. E. M. Coward, The Pharmacy, Stalbridge, Dorset.

Meetings: Charterhay, Stourton, Caundle, Dorset. 2nd Wednesday each month.

North Staffordshire Astronomical Society

Secretary: N. Oldham, 25 Linley Grove, Alsager, Stoke-on-Trent.

Meetings: 1st Wednesday of each month at Cartwright House, Broad Street, Hanley.

North Western Association of Variable Star Observers

Secretary: Jeremy Bullivant, 2 Beaminster Road, Heaton Mersey, Stockport, Cheshire.

Meetings: Four annually.

Norwich Astronomical Society

Secretary: Malcolm Jones, Tabor House, Norwich Road, Malbarton, Norwich.

Meetings: The Observatory, Colney Lane, Colney, Norwich. Every Friday, 7.30 p.m.

Nottingham Astronomical Society

Secretary: C. Brennan, 40 Swindon Close, Giltbrook, Nottingham.

- Oakham School Observing Society**
Secretary: M. A. Nowell, Chapel Close, Oakham School, Oakham, Rutland.
Meetings: As arranged.
- Oldham Astronomical Society**
Secretary: P. J. Collins, 25 Park Crescent, Chadderton, Oldham.
Meetings: Werneth Park Study Centre, Frederick Street, Oldham. Fortnightly, Friday.
- Open University Astronomical Society**
Secretary: Jim Lee, c/o above, Milton Keynes.
Meetings: Open University, Walton Hall, Milton Keynes. As arranged.
- Orpington Astronomical Society**
Secretary: Miss Lucinda Jones, 263 Crescent Drive, Petts Wood, Orpington, Kent.
Meetings: Newstead Wood School or Darrick Wood School, 3rd Thursday each month, Oct.–June, 7.30 p.m.
- Oxshott Astronomical Society**
Secretary: B. J. Donelan, Homelea, Portsmouth Road, Esher, Surrey.
Meetings: Reed's School, Sandy Lane, Cobham, Surrey. Monthly, Sept.–May.
- Peterborough Astronomical Society**
Secretary: E. Pitchford, 24 Cissbury Ring, Werrington, Peterborough.
Meetings: Peterborough Technical College. 2nd Tuesday, 3rd Thursday each month.
- Plymouth Astronomical Society**
Secretary: G. S. Pearce, 1 Valletort Cott, Millbridge, Plymouth.
Meetings: Y.W.C.A., Lockyer Street, Plymouth. Monthly.
- Portsmouth Astronomical Society**
Secretary: G. B. Bryant, 81 Ringwood Road, Southsea.
Meetings: Monday. Fortnightly.
- Preston & District Astronomical Society**
Secretary: P. Sloane, 77 Ribby Road, Wrea Green, Kirkham, Preston, Lancs.
Meetings: Moor Park (Jeremiah Horrocks) Observatory, Preston. 2nd Wednesday. Last Friday each month. 7.30 p.m.
- Rayleigh Centre Amateur Astronomical Society**
Secretary: Bernard R. Soley, 136 The Chase, Rayleigh, Essex.
Meetings: Fitzwimarc School, Hockley Road, Rayleigh. Every Wednesday, 8 p.m.
- Reading Astronomical Society**
Secretary: Mrs. Muriel Wrigley, 30 Amherst Road, Reading.
Meetings: St. Peter's Church Hall, Church Road, Earley. Monthly (3rd Sat.), 7–10 p.m.
- Renfrew District Astronomical Society (formerly Paisley A.S.)**
Secretary: Robert Law, 14d Marmion Court, Forkes, Paisley.
- Richmond & Kew Astronomical Society**
Secretary: Stewart T. McLaughlin, 46 Lingwell Rd, Tooting, London, SW17 7NJ.
Meetings: Richmond Adult & Community College, Parkshot, Richmond, Surrey
- Salford Astronomical Society**
Secretary: J. A. Handford, 45 Burnside Avenue, Salford 6, Lancs.
Meetings: The Observatory, Chaseley Road, Salford.
- Salisbury Plain Astronomical Society**
Secretary: R. J. D. Dias.
- Scarborough & District Astronomical Society**
Secretary: M. D. Wilson, 19 Ryefield Close, Eastfield, Scarborough, N. Yorks, YO11.
Meetings: North Riding College of Education, Filey Road, Wednesdays, Sept.–June, 7.30–9 p.m.
- Scottish Astronomers Group**
Secretary: G. Young c/o. Mills Observatory, Balgay Park, Ancrum, Dundee
Meetings: Bi-monthly, around the Country. Syllabus given on request.
- Sheffield Astronomical Society**
Secretary: Mrs Lilian M. Keen, 21 Seagrave Drive, Gleadless, Sheffield.
Meetings: City Museum, Weston Park, 3rd Friday each month. 7.30 p.m.
- Sidmouth and District Astronomical Society**
Secretary: M. Grant, Salters Meadow, Sidmouth, Devon.
Meetings: Norman Lockyer Observatory, Salcombe Hill. 1st Monday in each month.
- Solent Amateur Astronomers**
Secretary: R. Smith, 10 Lincoln Close, Woodley, Romsey, Hants.
Meetings: Room 2, Oaklands Community Centre, Fairisle Road, Lordshill, Southampton. 3rd Tuesday.
- Southampton Astronomical Society**
Secretary: C. R. Braines, 1a Drummond Road, Hythe, Southampton.
Meetings: Room 148, Murray Building, Southampton University, 2nd Thursday each month, 7.30 p.m.
- South Downs Astronomical Society**
Secretary: J. Green, 46 Central Avenue, Bognor Regis, West Sussex.
Meetings: Last Friday in each month.

South-East Essex Astronomical Society

Secretary: C. Jones, 92 Long Riding, Basildon, Essex.

Meetings: Lecture Theatre, Central Library, Victoria Avenue, Southend-on-sea. Generally 1st Thursday in month, Sept.–May.

South-East Kent Astronomical Society

Secretary: P. Andrew, 30 Reach Close, St Margaret's Bay, nr. Dover.

Meetings: Monthly.

Southern Astronomical Society

Secretary: G. T. Elston, 34 Plummer Road, Clapham Park, London SW4 8HH.

Meetings: As arranged.

South Lincolnshire Astronomical & Geophysical Society

Secretary: F. F. Bermingham, 19 Field Close, Gosberton, Spalding, Lincs.

Meetings: South Holland Centre, Spalding. 3rd Thursday each month, 7.30 p.m.

South London Astronomical Society

Chairman: P. Bruce, 2 Constance Road, West Croydon, CRO 2RS.

Meetings: Surrey Halls, Birfield Road, Stockwell, London, SW4. 2nd Tuesday each month, 8 p.m.

Southport, Ormskirk and District Astronomical Society

Secretary: J. T. Harrison, 92 Cottage Lane, Ormskirk, Lancs, L39 3NJ.

Meetings: Saturday evenings, monthly as arranged.

South Shields Astronomical Society

Secretary: H. Haysham, Marine and Technical College, St George's Avenue, South Shields, Co. Durham.

Meetings: Marine and Technical College. Each Thursday, 7.30 p.m.

South Somerset Astronomical Society

Secretary: G. McNelly, 11 Laxton Close, Taunton. Somerset.

Meetings: The Victoria Inn, Skittle Alley, East Reach, Taunton. Last Saturday each month, 7.30 p.m.

South West Cotswolds Astronomical Society

Secretary: C. R. Wiles, Old Castle House, The Triangle, Malmesbury, Wilts.

Meetings: 2nd Friday each month, 8 p.m. (Sept.–June).

South West Herts Astronomical Society

Secretary: Frank Phillips, 54 Highfield Way, Rickmansworth, Herts

Meetings: Rickmansworth. Last Friday each month, Sept.–May.

Stafford and District Astronomical Society

Secretary: Mrs L. Hodgkinson, Beecholme, Francis Green Lane, Penkridge, Staffs.

Meetings: Riverside Centre, Stafford. Every 3rd Thursday, Sept.–May, 7.30 p.m.

Stirling Astronomical Society

Secretary: R. H. Lynn, 25 Pullar Avenue, Bridge of Allan, Stirling.

Meetings: Old Stirling High School, Academy Road, Stirling. Last Tuesday each month. 7.30 p.m.

Stoke-on-Trent Astronomical Society

Secretary: M. Pace, Sundale, Dunnocksfold Road, Alsager, Stoke-on-Trent.

Meetings: Cartwright House, Broad Street, Hanley. Monthly.

Sussex Astronomical Society

Secretary: Mrs C. G. Sutton, 75 Vale Road, Portslade, Sussex.

Meetings: English Language Centre, Third Avenue, Hove. Every Wednesday, 7.30–9.30 p.m. Sept.–May.

Swansea Astronomical Society

Secretary: G. P. Lacey, 32 Glenbran Road, Birchgrove, Swansea.

Meetings: Dillwyn Llewellyn School, John Street, Cockett, Swansea. Second and fourth Thursday each month at 7.30 p.m.

Thames Valley Astronomical Group

Secretary: K. J. Pallet, 82a Tennyson Street, South Lambeth, London, SW8 3TH.

Meetings: Irregular.

Thanet Amateur Astronomical Society

Secretary: P. F. Jordan, 85 Crescent Road, Ramsgate.

Meetings: Hilderstone House, Broadstairs, Kent. Monthly.

Todmorden Astronomical Society

Secretary: Eric Lord, Sloterdisk, 15 Mons Road, Todmorden, Lancashire.

Meetings: Monthly at Todmorden College.

Torbay Astronomical Society

Secretary: R. Jones, St Helens, Hermose Road, Teignmouth, Devon.

Meetings: Town Hall, Torquay. 3rd Thursday, Oct.–May.

Usk Astronomical Society

Secretary: D. J. T. Thomas, 20 Maryport St, Usk, Gwent.

Meetings: Usk Adult Education Centre, Maryport St., Weekly, Thursdays (term dates).

Vectis Astronomical Society

Secretary: J. W. Smith, 27 Forest Road, Winford, Sandown, I.W.

Meetings: 4th Friday each month, except Dec. at Lord Louis Library Meeting Room, Newport, I.W.

Waltham Forest & District Junior Astronomy Club

Secretary: B. Crawford, 24 Fulbourne Road, Walthamstow, London, E.17.

Meetings: 24 Fulbourne Road, Walthamstow, London, E.17. Fortnightly (Mondays).

Warwickshire Astronomical Society

Secretary: R. D. Wood, 20 Humber Road, Coventry, Warwickshire.

Meetings: 20 Humber Road, Coventry. Each Tuesday.

Webb Society

Secretary: S. J. Hynes, 8 Cormorant Close, Sydney, Crewe, Cheshire.

Meetings: As arranged.

Wellingborough District Astronomical Society

Secretary: S. M. Williams, 120 Brickhill Road, Wellingborough, Northants.

Meetings: on 2nd Wednesday. Gloucester Hall, Church Street, Wellingborough, 7.30 p.m.

Wessex Astronomical Society

Secretary: Mrs J. Broadbank, 154a Albert Road, Parkstone, Poole, Dorset, BH12 2HA.

Meetings: The Cafe Lounge, Allendale Centre, Wimborne, Dorset. 1st Tuesday of each month (except August).

West of London Astronomical Society

Secretary: A. H. Davis, 49 Beaulieu Drive, Pinner, Middx, HA5 1NB.

Meetings: Monthly, alternately at Hillingdon and North Harrow. 2nd Monday of the month, except August.

West Midland Astronomical Association

Secretary: Miss S. Bundy, 93 Greenridge Road, Handsworth Wood, Birmingham.

Meetings: Dr Johnson House, Bull Street, Birmingham. As arranged.

West Yorkshire Astronomical Society

Secretary: J. A. Roberts, 76 Katrina Grove, Purston Pontefract, Yorks, WF7 5LW.

Meetings: The Barn, 4 The Butts, Back Northgate, Pontefract. Every Tuesday, 7 p.m.

Widnes Astronomical Society

Secretary: Miss A. Williams, 21 Deansway, Ditton, Widnes.

Meetings: To be arranged.

Wolverhampton Astronomical Society

Secretary: M. Astley, Garwick, 8 Holme Mill, Fordhouses, Wolverhampton.

Meetings: Beckminster Methodist Church Hall, Birches Road, Wolverhampton. Alternate Mondays, Sept.-April.

Worcester Astronomical Society

Secretary: Ian Crenwell, 25 Meadow Road, Worcester.

Meetings: Room 117, Worcester College of Higher Education, Henwick Grove, Worcester. 2nd Thursday each month.

Wycombe Astronomical Society

Secretary: P. A. Hodgins, 50 Copners Drive, Holmer Green, High Wycombe, Bucks.

Meetings: 3rd Wednesday each month. 7.45 p.m.

York Astronomical Society

Secretary: Olav Wilde, 6 Sussex Road, Badger Hill, York.

Meetings: Goodricke College, York University. 1st and 3rd Fridays.

Any society wishing to be included in this list of local societies or to update details are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1A 2SG.), so that the relevant information may be included in the next edition of the *Yearbook*.

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